

Phase II RCRA Facility Investigation

East Helena Facility

DRAFT

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Prepared by



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Limitations

This Phase 2 RFI Report was prepared by GSI Water Solutions Inc. (GSI), for use by the Montana Environmental Trust Group (METG), U.S. Environmental Protection Agency and the State of Montana. The information presented in this RFI Report was collected by others during a 20+ year period, and was compiled by others in various databases, electronic files, reports throughout this period. GSI and others relied upon this information for our descriptions of historical and current site conditions. Our scope of work did not include a comprehensive quality control/quality assurance (QA/QC) evaluation of the existing information, and, therefore, GSI cannot verify its accuracy. Within the limitations of the scope, schedule, and budget our services have been conducted in accordance with the generally accepted environmental and hydrogeologic practices at the time this report was prepared.

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Acronyms

3-D	three-dimensional
AOPC	areas of potential concern
APSD	Acid Plant Sediment Drying
Asarco	Asarco, LLC
BERA	Baseline Ecological Risk Assessment
bgs	below ground surface
CAMU	Corrective Action Management Unit
CC/RA	Current Conditions/Release Assessment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic ft per second
CMS	Corrective Measures Study
COC	contaminant of concern
COI	contaminant of interest
COPC	contaminant of potential concern
CSBH	Concentrate Storage and Handling Building
CSM	conceptual site model
DMR	Daily monitoring report
DRO	diesel range organics
EH	East Helena
EMPA	electron microprobe analysis
EPA	U.S. Environmental Protection Agency
EPH	extractable petroleum hydrocarbon
EPC	exposure point concentration
F	Fahrenheit
FS	feasibility study
FSAP	Field Sampling and Analysis Plan
gpm	gallons per minute
GPS	global positioning system
GRO	gasoline range organics
GWSWI	groundwater/surface water interaction
HDPE	high-density polyethylene
HDS	high density sludge
HHRA	Human Health Risk Assessment

HQ	Hazard Quotient
ID	inside diameter
IRAM	interim remedial action measures
LOAEL	Lowest Observed Adverse Effect Level
MBMG	Montana Bureau of Mines and Geology
MCL	Maximum Contaminant Level
MDEQ	Montana Departments of Environmental Quality
MDOJ	Montana Department of Justice
METG	Montana Environmental Trust Group, LLC
MFWP	Montana Department of Fish, Wildlife and Parks
mg/L	milligrams per liter
MNHP	Montana Natural Heritage Program
MNRD	Natural Resource Division
MPDES	Montana Pollutant Discharge Elimination System
mph	miles per hour
NOAEL	No Observed Adverse Effect Level
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRD	Montana Natural Resource Division
ORP	oxidation reduction potential
OSHA	Occupational Safety and Health Administration
OU	operable unit
PEC	Probable Effect Concentration
PRB	Permeable reactive barrier
PVC	polyvinyl chloride
QA/QC	Quality Control/Quality Assurance
QAPP	Quality Assurance Program Plan
RCRA	Resource Conservation and Recovery Act
RFI	Resource Conservation and Recovery Act Facility Investigation
RI	remedial investigation
RI/FS	remedial investigation/feasibility study
ROD	Record of Decision
RSL	Regional Screening Level
SLV	screening level value
SMCL	Secondary Maximum Contaminant Level

SPLP	Synthetic Precipitation Leachate Procedure
SQG	Sediment Quality Guideline
SSL	soil screening level
SWL	static water level
SWPPP	Stormwater Pollution Prevent Plan
TCLP	Toxic Characteristic Leaching Procedure
TDS	total dissolved solids
TEC	Threshold Effect Concentration
TMDL	total maximum daily load
TOC	total organic carbon
TRV	Toxicity Reference Value
TSS	total suspended solids
UCL	upper confidence limit
µg/L	micrograms per liter
USFWS	U.S. Fish and Wildlife Service
VPH	volatile petroleum hydrocarbon
XAS	X-ray absorption spectroscopy
ZVI	zero-valent iron

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Executive Summary

This document presents the results of the Phase II Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) for the former Asarco smelter ("the Facility") located in the City of East Helena, Montana. Asarco operated a custom lead smelter from 1888 to 2001 and produced lead bullion from the smelting of a variety of foreign and domestic concentrates, ores, fluxes, and other non-ferrous metal bearing materials. Plant operations were suspended in April 2001. Ownership of the Facility was transferred to the Montana Environmental Trust Group (METG), LLC, as Trustee for the Montana Environmental Custodial Trust, in December 2009 as part of the larger Asarco bankruptcy settlement agreement.

Background

The U.S. Environmental Protection Agency (EPA) proposed the Facility for listing on the National Priorities List (i.e., Superfund sites) in September 1983, based primarily on the presence of contaminated soils in residential areas in the City of East Helena. EPA issued a Record of Decision (ROD) in November 1989 that selected a remedy that required (1) groundwater pollution from onsite process ponds be reduced by isolating the process waters from groundwater and (2) contaminated soils and pond sediments be removed. In July 1991, Asarco began removal of contaminated soil from residential areas, parks, playgrounds, streets, and alleys in the City of East Helena. In 2006, an EPA ROD deemed that the cleanup of residential soil was protective of human health.

While the federal CERCLA program was initially the governing authority for cleanup of residential and agricultural soils, and surface water or surface water sources, the Facility was regulated under the federal RCRA program while it was operating. In 1997, EPA initiated transfer of responsibility for ongoing remedial activities at the Facility from its CERCLA program to its "corrective action" program under RCRA. A Consent Decree, effective May 5, 1998, initiated the RCRA corrective actions process, with the primary focus of further investigation of contamination in groundwater, surface water, and soils, and in the former ore storage areas. Ongoing remediation of the Facility continues under RCRA authority. EPA determined that an RFI was required for the Facility, with the RFI to be conducted in two phases. Phase I of the RFI was conducted in 2000 and Phase II of the RFI was initiated in 2010.

Previous investigations documented metals and other contaminant releases to the environment (soil, air, groundwater, surface water, sediments, and stormwater) as a result of historical activities at the Facility. While remedial measures have been implemented at the Facility, elevated contaminant concentrations remain in onsite soil, groundwater, and sediments.

Site Setting

The 142-acre Facility is located within the Helena Valley approximately 3 miles east of the City of Helena. The Facility is located primarily on the Prickly Pear Creek alluvial plain and

is bounded to the north by Highway 12, the City of East Helena, and American Chemet; to the south by Upper Lake, Upper Lake Marsh, and Lower Lake; to the east and northeast by Prickly Pear Creek; and to the west and southwest by open agricultural land and the Manlove neighborhood. The most prominent site feature is a slag pile that currently occupies 35 acres in the northeastern portion of the Facility.

Nearby land uses include residential and commercial areas in the City of East Helena, rural residential areas in nearby subdivisions, and agricultural land and rangeland. Land uses at the Facility and adjacent American Chemet site are classified as industrial. Current human use of the site is minimal because the Facility was shut down in 2001 and the main site use is associated with environmental cleanup activities. Public access to the Facility is restricted by fencing. Many buildings have been demolished and some contaminated soils beneath buildings have been excavated and disposed of in onsite CAMUs; residual contamination currently is capped with temporary high-density polyethylene liners.

Current and future residents in areas surrounding the Facility may contact groundwater, windblown dust, surface water, or sediment in creeks and ditches that contain contaminants derived from the Facility. Many rural residents in the Helena Valley (including the outlying areas around the Cities of Helena and East Helena) rely solely on private wells for their water supply.

Environmental Setting

Terrestrial habitat in and near the Facility, which includes vegetated upland areas outside the Facility perimeter, the sparsely vegetated area between Lower and Upper Lakes (referred to as Tito Park), and the riparian corridor along Prickly Pear Creek, provides habitat for deer, small mammals, and upland game birds and support livestock (primarily cattle). Within the Facility, habitat is limited by notable human disturbance.

Aquatic habitats within and near the Facility exist in Prickly Pear Creek, Upper Lake and Upper Lake Marsh, Lower Lake, and Wilson Ditch. Upper Lake, Upper Lake Marsh, and Prickly Pear Creek provide a diverse range of habitats for benthic invertebrates, fish, amphibians, and aquatic plants. Lower Lake and Wilson Ditch (which flows seasonally) are man-made structures with lower quality habitat.

The 2010 Baseline Ecological Risk Assessment (BERA) concluded that many upland and aquatic habitat areas have contaminant concentrations in soil, sediment, and surface water that pose unacceptable risk to terrestrial and aquatic ecological receptors. The contaminants of concern (COC) for ecological receptors are arsenic, cadmium, mercury, lead, selenium, antimony, manganese, silver, thallium, and zinc. Areas of unacceptable terrestrial risks include uplands along the East and West Perimeter of the Facility. Risks to aquatic species were identified in Upper Lake and Upper Marsh where suitable habitat exists.

Hydrogeologic Setting

The hydrogeologic framework is divided into three main hydrostratigraphic units:

- **Upper Aquifer** - This Upper Aquifer is the main focus of the groundwater investigation and the vast majority of the monitoring wells are completed in this unit. The Upper Aquifer is composed of silt and gravel, which varies in thickness

from about 20 feet at the south end of the Facility to nearly 80 feet at the north end of Lamping Field.

- **Aquitard** - This unit, where present, marks the base of the Upper Aquifer and separates it from the underlying groundwater unit. The depth to the Aquitard unit increases from about 20 feet bgs at the south end of the Facility, 50 feet bgs at the north end of the Facility site, and 80 feet bgs at the north end of Lamping Field. The thickness of this unit is estimated to be approximately 12 feet near the middle of the Facility (DH-18).
- **Deeper Groundwater System** - This system lies beneath the Aquitard unit. Because the RFI and previous work have focused on the Upper Aquifer, the thickness and hydrologic properties of the Deeper Groundwater System are largely unknown.

Groundwater beneath the Facility flows to the north/northwest and continues in a northwesterly direction offsite. Seepage from Upper Lake and Lower Lake on the southern property margin provides a significant source of recharge to the groundwater system, and provides a driving head that impacts groundwater flow gradients and velocities. Seepage from Prickly Pear Creek, Wilson Ditch, and unlined irrigation ditches also provides localized recharge to the Upper Aquifer. Recharge from Prickly Pear Creek creates a flow divide at least as far north as Lamping Field that acts as a boundary, restricting eastward migration of groundwater and contaminants downgradient of the Facility.

Current Contaminant Conditions

The Phase II RFI was designed to describe current conditions, provide information required to support risk management decisions in connection with the Custodial Trust's obligations under the 1998 RCRA Consent Decree, and support the evaluation and selection of appropriate corrective measures to protect human health and the environment. The Phase II RFI represents a continuation of previous site characterization and evaluation programs, most notably the *Comprehensive Remedial Investigation and Feasibility Study* (RI/FS or *Comprehensive RI/FS*); *Current Conditions/Release Assessment* (CC/RA), and the *Phase I RFI*, and relies heavily on data and information obtained through these previous efforts.

Soil

Surface and subsurface soil contamination is significant and widespread throughout the Facility at concentrations up to approximately 1,800 times higher than levels considered protective of human health (e.g., industrial screening level values [SLV]). Leaching of antimony, arsenic, cadmium, copper, lead, manganese, mercury, and selenium from surface and subsurface soil poses a widespread threat to groundwater quality within the Facility. Based on the results of the leaching tests, arsenic and selenium are the soil contaminants that have the greatest impact on groundwater quality. The following are key findings:

- Saturated zone soils appear to be the most significant ongoing source of arsenic loading to groundwater in the southern half of the Facility, particularly the Acid Plant, Speiss-Dross, and Tito Park areas.

- Unsaturated zone soils also may be a source of arsenic to groundwater in certain areas of the Facility. High concentrations of arsenic in soils and leachate were obtained near the Acid Plant and Tito Park areas, which have relatively shallow groundwater.
- Saturated soil may be the source of the lower concentration portions of the selenium plume. Phase II RFI testing indicates leachate from Acid Plant soil is greater than the selenium groundwater SLV, a result consistent with groundwater selenium SLV exceedances in this area of the Facility.
- Unsaturated soils also may be a source of the lower concentration portions of the selenium plume based on (1) the relatively high selenium concentrations found in soils at some surface soil sampling locations (e.g. upgradient of the thaw house and concentrate storage and handling building), and (2) leach testing that indicates unsaturated zone soils in this area may leach selenium in significant quantities.
- Slag is capable of leaching selenium at concentrations that exceed the groundwater SLV. The higher leachable concentrations of selenium from slag correlate with total concentrations, and occur in the central upper lift of the slag pile. This is the most recent slag added to the pile. Evidence for slag as a source includes the spatial distribution of selenium and potassium in groundwater in the eastern lobe of the selenium plume. The importance of slag will need to be evaluated further during calibration of the flow and transport model.

Stormwater

Stormwater across much of the site is captured by a series of interconnected catch basins, temporarily stored in tanks, and treated at the site's water treatment facility. Stormwater collection and treatment is an important engineering control because samples of untreated stormwater from sumps and other locations across the Facility commonly showed SLV exceedances for arsenic, cadmium, and lead. Copper and selenium concentrations exceeded the project screening value in one sample from the Ore Storage Yard. The water treatment facility appears to be effective for most contaminants, with the exception of periodic detections of selenium in the effluent above the project stormwater SLV (13 of 66 samples between 2001 and 2010). Treated stormwater is discharged to Lower Lake under the Facility's Montana Pollutant Discharge Elimination System permit.

Ongoing stormwater management will be an important component of future corrective measures at the Facility to prevent uncontrolled runoff, minimize the infiltration of precipitation and leaching of contaminants to groundwater, and provide suitable treatment to allow discharge without degrading surface water.

Surface Water

Dissolved concentrations of arsenic, cadmium, iron, lead, selenium, and zinc were detected in one or more surface water sample locations at concentrations exceeding the project SLVs. Contaminant concentrations in samples collected from Upper Lake and/or Lower Lake, on either side of Tito Park, were significantly elevated in arsenic, cadmium, lead, and zinc. It is notable that dissolved contaminant of potential concern (COPC) concentrations measured in samples from Wilson Ditch are generally less than project SLVs.

Site data clearly show that Upper Lake and Lower Lake are significant sources of recharge to the Upper Aquifer. This will be an important consideration in designing future groundwater remedial measures. Surface water in Lower Lake is an ongoing low-level (0.1 mg/L) source of arsenic to groundwater. Some slag also produces leachate at concentrations that exceed the SLV for arsenic. The importance of these potential sources for ongoing loading will need to be evaluated further during calibration of the flow and transport model.

While most of Prickly Pear Creek is a losing stream above and below the Facility, an analysis of groundwater and surface water levels shows that the reach in the immediate vicinity of Lower Lake gains flow from groundwater discharge. Elevated arsenic concentrations in groundwater in this area suggest that groundwater is a likely source of arsenic to Prickly Pear Creek. Downstream (north) of the Facility, Prickly Pear Creek is a losing stream.

Streamflow hydrographs of wells in the vicinity of Wilson Ditch show a rapid response to operation of the ditch, indicating a strong connection between the ditch and groundwater. Ditch losses of between 0.6 and 1.4 cubic feet per second (cfs) to groundwater were measured during summer 2010 operations. Hydrographs for wells completed in the Upper Aquifer and Deeper Groundwater System responded to flow in Wilson Ditch.

Groundwater

Within the Facility, the following dissolved metals were detected in the Upper Aquifer above project SLVs and, therefore, are identified as COPCs for groundwater: aluminum, antimony, arsenic, cadmium, lead, manganese, mercury, selenium, thallium, vanadium, and zinc. Of these, arsenic and selenium have the greatest number of SLV exceedances. Selenium is a highly mobile contaminant and has the largest plume footprint. As groundwater migrates northward away from the Facility, concentrations of COPCs decrease and the number of SLV exceedances decrease. Offsite exceedance of groundwater SLVs are limited to antimony, arsenic, manganese, and selenium. Of these contaminants, antimony and manganese exceedances are restricted to a limited number of wells and these occur in areas encompassed by the arsenic and selenium plumes. The vertical extent of contamination appears restricted to the Upper Aquifer.

Selected residential and public water supply wells are being sampled regularly as part of the ongoing groundwater monitoring program to ensure protection of groundwater users downgradient of the Facility. Data collected to date indicate that the City of East Helena's public water supply wells downgradient of the Facility have not been impacted by releases from the site.

A key conclusion of the groundwater investigation is that arsenic and selenium are the primary COPCs for groundwater because the extent of these plumes above project SLVs encompasses all other site-related contaminants. Based on this conclusion, a more detailed analysis of the sources, fate and transport of arsenic and selenium in groundwater, was conducted in Section 11 of the Phase RFI Report. Key findings and conclusions of this analysis are:

- The lateral extent of the arsenic plume appears to be relatively stable. This is primarily the result of mineral sequestration (attenuation) during groundwater flow.

Comparison of historical and recent arsenic data show the highest concentration onsite areas of the plume have contracted during the last 8 to 10 years because process water, which was the primary source of arsenic, was eliminated in 2001. The depth-distribution of arsenic in saturated soils shows that arsenic has not appreciably penetrated the underlying Aquitard.

- The primary source of selenium is historical discharges of site process water. Evidence that supports this hypothesis includes the reportedly high concentrations of selenium in process water, and maximum site concentrations that coincide with other conservative tracers of process water (sulfate and chloride).
- Selenium is more mobile than arsenic in groundwater, and, therefore, the footprint of the downgradient plume is larger than arsenic. The transient nature of the plume is consistent with the predominant chemical form of selenium in groundwater being Se(VI), the most mobile redox species. Because of the conservative (highly mobile) nature of this contaminant, dissolved selenium continues to migrate in groundwater downgradient of the Facility. This behavior contrasts with arsenic, which tends to be sequestered by minerals in the aquifer matrix.
- The mapped downgradient extent of selenium with a Facility source-signature extends more than 2 miles downgradient of the Facility and is further empirical evidence of the mobile nature of this contaminant. However, it is important to note that selenium concentrations at downgradient margins of the plume are below project SLVs. The vertical extent of the selenium is also more expansive than arsenic. Additional monitoring of the Deeper Groundwater System is recommended to evaluate the presence or absence of selenium in the Deeper Groundwater System.
- There are insufficient historical selenium data downgradient of the Facility to draw firm conclusions about trends in concentrations at the downgradient plume margin. Whether the currently defined 0.05 mg/L selenium plume reaches downgradient locations most likely will depend on physical processes of dilution and dispersion because attenuation of the dominant aqueous species (Se(VI)) is expected to be small. This hypothesis can be tested during calibration of the flow and transport model.

1 Introduction

This document presents the results of the Phase II Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) for the former Asarco smelter ("the Facility," "plant site," "site") located in the City of East Helena, Montana (Figure 1-1). Asarco operated a custom lead smelter from 1888 to 2001 and produced lead bullion from the smelting of a variety of foreign and domestic concentrates, ores, fluxes, and other non-ferrous metal bearing materials. In addition to lead bullion, the Facility produced copper by-products and food-grade sulfuric acid (Hydrometrics, 2010a). Plant operations were suspended in April 2001, and in August 2005 Asarco (i.e., Asarco, LLC) filed for Chapter 11 bankruptcy. Ownership of the Facility was transferred to the Montana Environmental Trust Group (METG), LLC, as Trustee for the Montana Environmental Custodial Trust ("the Custodial Trust"), in December 2009 as part of the larger Asarco bankruptcy settlement agreement (see Section 1.2).

Elevated metals concentrations have been identified in soil, groundwater, surface water, sediment, and stormwater at the Facility. The Phase II RFI has been designed to provide information required to support risk management decisions in connection with the Custodial Trust's obligations under the 1998 RCRA Consent Decree (U.S. District Court, 1998) and to support the evaluation and selection of appropriate corrective measures to protect human health and the environment.

Metals and other contaminants have been released to the environment (soil, air, groundwater, surface water, sediments, and stormwater) as a result of historical activities at the Facility. While remedial measures have been implemented at the Facility, as described in Section 2, elevated contaminant concentrations remain in onsite soil, groundwater, and sediments. Surface and subsurface soils contain elevated concentrations of contaminants including, but not limited to, arsenic, cadmium, copper, lead, and zinc. Groundwater contaminant plumes (e.g., arsenic, selenium, sulfate) extend offsite to the north and northwest from the Facility, thereby posing a possible threat to human health and the environment.

The U.S. Environmental Protection Agency (EPA) and the Montana Department of Environmental Quality (MDEQ) required Asarco to perform numerous site investigation programs and remediation activities at the Facility to address metals-impacted soils and groundwater. The Custodial Trust has assumed responsibility for completing these activities at the Facility.

The Phase II RFI was conducted in accordance with the *Phase II RFI Site Characterization Work Plan* (Hydrometrics, 2010a) and with EPA guidance (EPA, 1989b). The Phase II RFI represents a continuation of previous site characterization and evaluation programs, most notably the *Comprehensive Remedial Investigation and Feasibility Study* (RI/FS or *Comprehensive RI/FS*; Hydrometrics, 1990), *Current Conditions/Release Assessment* (CC/RA; Hydrometrics, 1999a), and the *Phase I RFI* (ACI, 2005), and relies heavily on data and information obtained through these previous efforts.

1.1 Purpose and Objectives

The purpose of the RFI is to document current Facility conditions to support the selection of appropriate remedial actions to ensure protection of human health and the environment. Specific objectives of this document include:

1. Describing the current nature and extent of contaminants (i.e., releases of hazardous wastes and/or hazardous constituents) associated with the Facility in soil, groundwater, surface water, sediment, and stormwater.
2. Identifying contaminants of potential concern (COPC) at the Facility.
3. Identifying potential areas of potential concern (AOPC).
4. Evaluating the fate and transport of Facility-related contaminants.
5. Supporting the completion of the *Human Health Risk Assessment (HHRA)*, *Baseline Ecological Risk Assessment (BERA)*, *Corrective Measures Study (CMS)*, and the groundwater flow and contaminant transport model.
6. Supporting the identification of areas that may be suitable for implementing interim remedial action measures (IRAM).

Major environmental remediation has been performed at the Facility during the last 20 years; however, environmental problems persist in specific locations at the Facility and in the groundwater, both on and off the Facility. Elevated contaminant concentrations continue to exist in groundwater and in site soils. Arsenic and selenium have migrated offsite through groundwater transport at concentrations exceeding relevant water quality standards, posing a possible threat to human health and the environment. The sources and geochemical behavior of the arsenic and selenium groundwater plumes require further refinement to allow evaluation of potential corrective measures.

1.2 Montana Environmental Trust Group

METG is the Trustee of the Montana Environmental Custodial Trust (the Custodial Trust) and was created for the purpose of funding and managing the former Asarco lead smelter in the City of East Helena and the affiliated mining sites in Montana. The Custodial Trust, established in December 2009 as a result of the Asarco bankruptcy settlement, has responsibility for operational, cleanup, and revitalization activities at the sites under the oversight of the EPA and MDEQ, Montana Department of Justice, and Montana Natural Resource Division (METG, 2011a).

The Custodial Trust's responsibilities are performed in compliance with the terms of the Settlement Agreement and Consent Decree Regarding Montana Sites and are consistent with Custodial Trust's fiduciary obligations to the United States and the State of Montana — the sole beneficiaries (Beneficiaries) of the Custodial Trust. Additionally, the Custodial Trust must fulfill Asarco's cleanup obligations set forth in a 1998 Consent Decree, as modified, between the United States and Asarco LLC, et al. (Civil Action No. CV-98-3-H-CCL-US federal District Court, District of Montana) as a result of claims brought against Asarco by the United States pursuant to RCRA (METG, 2011a).

Asarco transferred title to about 3,980 acres (plus about 2,000 acres of unpatented mining claims) at the four sites in Montana on December 9, 2009, to METG as Trustee of the Custodial Trust, and deposited approximately \$138 million into the Custodial Trust for cleanup work. Asarco also transferred an additional \$39.5 million directly to the State of Montana for natural resource damages. In addition to the funding, the State of Montana also will be given 232 acres of Asarco's land (now held by the Custodial Trust) after it is cleaned up, including wetlands along Prickly Pear Creek near the smelter site in the Helena Valley (METG, 2011a)

About \$94 million of the funds transferred to the Custodial Trust are earmarked for the site, for treatment of arsenic- and selenium-contaminated groundwater migrating off the Facility northwest toward the Helena Valley, and for stabilizing, controlling, and/or removing lead- and arsenic-contaminated soils on approximately 1,500 acres of former Asarco property. These lands also include ranches and farmland that encircle three quarters of the smelter property that were purchased because of concerns that contamination might be affecting the growing and grazing uses of the property (METG, 2011a).

Through the federal RCRA and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; Superfund) programs, the EPA has lead agency responsibility for enforcement and oversight of the Facility. While the Custodial Trust has taken title to the property, the Custodial Trust is acting solely as a fiduciary for the benefit of the Beneficiaries (METG, 2011a).

1.3 Report Organization

This Phase II RFI report was prepared in accordance with the EPA-approved *Phase II RFI Site Characterization Work Plan* (Hydrometrics, 2010a) and with EPA guidance (EPA, 1985a, 1985b, 1985c, 1986a, 1986b, 1986c, 1986d, 1987, 1988, 1989b). The report is organized to generally follow the outline provided in EPA RFI guidance and includes the following sections:

- *Section 2. Site Description and Background*
This section provides a summary of the historical smelter operations, known onsite sources of contaminants, the regulatory history of the Facility, and previous environmental investigations and remedial actions performed on the site.
- *Section 3. Environmental Setting*
This section presents a summary of the climate, topography, surface water hydrology, ecosystems, and potential current and future receptors in the vicinity of the Facility.
- *Section 4. Phase II RFI Investigation*
This section summarizes the scope of the Phase II RFI, discusses the sources of data evaluated for this report and the process for screening site contaminant concentrations to identify COPCs and APOCs. The following sections describe the approach, analyses, and the results of the Phase II RFI by media.

- *Section 5. Geology and Hydrogeology*

This section presents a discussion of regional and site geologic and hydrogeologic conditions.

- *Section 6. Soil*

This section presents a summary of results from previous soil investigations, the results of the Phase II RFI and BERA (Gradient, 2010b) soil sampling, the distribution of soil contamination, contaminant screening, identification of COPCs and AOPCs in soil, and a discussion of contaminant fate and transport.

- *Section 7. Groundwater*

This section presents a summary of results from previous groundwater investigations, the results of the Phase II RFI groundwater sampling, the extent of groundwater contamination, contaminant screening, identification of COPCs and AOPCs in groundwater, and a discussion of groundwater contaminant fate and transport.

- *Section 8. Surface Water*

This section presents a summary of results from previous surface water investigations, the results of the Phase II RFI and BERA (Gradient, 2010b) surface water sampling, the distribution of surface water contamination, contaminant screening, identification of COPCs and AOPCs in surface water, and a discussion of contaminant fate and transport.

- *Section 9. Sediment*

This section presents a summary of results from previous sediment investigations, the results of the Phase II RFI and BERA (Gradient, 2010b) sediment sampling, the distribution of surface water contamination, contaminant screening, identification of COPCs and AOPCs in surface water, and a discussion of contaminant fate and transport.

- *Section 10. Stormwater*

This section presents a summary of results from previous stormwater investigations, the results of the 2010 stormwater sampling (Hydrometrics, 2010b), the distribution of stormwater contamination, contaminant screening, and a discussion of contaminant fate and transport.

- *Section 11. Contaminant Fate and Transport*

This section presents a discussion of contaminant migration mechanisms, contaminant properties, soil and groundwater chemistry, and an evaluation of the fate and transport of selected contaminants in Facility media (e.g. soil, groundwater, sediment).

- *Section 12. Groundwater Flow and Contaminant Transport Model*

This section provides an overview of the groundwater and contaminant transport models that are currently being developed to evaluate hydrologic conditions at the Facility, groundwater plume stability, and potential remedial options in the CMS and to support remedial action decisions.

- *Section 13. Conclusions and Recommendations*

This section summarizes the key findings and conclusions, based on the results of the Phase II RFI and evaluation of applicable Facility data.

- *Section 14. References*

This section provides specific references cited in this document and general references that may be useful in further understanding the history or environmental conditions at the Facility.

1.4 Relationship to Other Key Documents/Programs

This report presents the findings from the second of the two phases of the EPA-required RFI for the Facility. The *Phase I RFI* included further site characterization and investigation for the purpose of providing sufficient data for development of corrective measures alternatives (Hydrometrics, 2000a). The Phase II RFI is intended to describe the current nature and extent of contaminants present at the Facility and to support activities currently being performed under EPA and MDEQ's hazardous waste (e.g., RCRA), cleanup (e.g., CERCLA) and stormwater (e.g., National Pollutant Discharge Elimination System [NPDES] programs). The following activities are currently underway or planned at the Facility:

- Ensuring regulatory requirements (e.g., associated with NPDES permit, consent degrees) are met.
- Completing the BERA to identify potential risks to ecological receptors (Gradient, 2010b).
- Evaluating potential risks to human health in the HHRA.
- Preparing a CMS work plan to describe how potential remedial actions will be evaluated to support the selection of final remedial action for the Facility, ensuring that nearby residents and ecological receptors are protected and allowing Trust-owned property to be redeveloped for beneficial use.
- Identifying actions needed to ensure that current and future beneficial uses of groundwater are protected (e.g., use of groundwater as a drinking water resource, recharge to surface water bodies).
- Developing a groundwater flow and contaminant fate and transport model to evaluate groundwater plume stability and remedial action effectiveness (see Section 12) and support risk management decisions by METG and the Beneficiaries.
- Identifying and evaluating areas onsite where IRAMs may be warranted to reduce risks to human health or the environment or to control contaminant sources.
- Identifying data needed to complete the evaluation of the HHRA, CMS, groundwater model, etc. (i.e., data gaps).
- Optimizing the groundwater and surface water monitoring programs.

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2 Site Description and Background

2.1 Location

The Facility occupies approximately 142 acres within the Helena Valley, which is situated in Lewis and Clark County, and is located approximately 3 miles east of the City of Helena. The Facility is bounded to the south by Upper Lake, Upper Lake Marsh, and Lower Lake; to the east and northeast by Prickly Pear Creek; and on the west and southwest by uplands or foothills. State Highway 12 (Highway 12) and the American Chemet facility (a manufacturer and marketer of metals-based chemicals) border the Facility on the north. The City of East Helena is located a short distance to the north, on the north side of Highway 12. The Facility and surrounding features are shown in Figure 1-1.

2.2 Land Use and Ownership

Land uses in the Facility area include established residential and commercial areas in the City of East Helena, rural residential areas in nearby subdivisions, and agricultural land and rangeland. Land-use designations in the Facility area are shown in Figure 2-1. Land use at the Facility and adjacent American Chemet site is classified as industrial. Former smelter operations at the Facility ended in 2001, and current land use at the Facility includes investigations and remediation activities under the federal Superfund program (e.g., investigation of arsenic- and selenium-contaminated groundwater migrating offsite from the Facility, removal of contaminated soils; see Section 2.3). Public access to the Facility is restricted by fencing.

2.2.1 METG Land Ownership

In conjunction with the December 2009 bankruptcy proceedings, METG acquired ownership of the 142-acre Facility for purposes of remediation under EPA oversight, as described in Section 1.2. As part of this transaction, METG also acquired approximately 1,360 acres (approximately 1,500 acres in total, see Figure 2-1) of ranchland and agricultural land surrounding the Facility that were purchased because of concerns that contamination might be affecting the growing and grazing uses of the property (METG, 2011a).

2.2.2 Ownership of Surrounding Properties

The City of East Helena has a population of approximately 1,540 (Sperlings, 2011) and lies adjacent to several residential subdivisions that have an additional estimated population of 2,500 (Hydrometrics, 1999a). Subdivisions located closest to the Facility include Seaver Park and Manlove. These developed residential and commercial areas include privately owned and municipal properties (see Figure 2-1). The industrial property to the north of the Facility is owned and operated by the American Chemet Corporation.

2.3 Background

2.3.1 Smelter Operations

The Asarco East Helena Facility was constructed in 1888 by the Helena and Livingston Smelting and Reduction Company for the purpose of processing ores from local mines. The Facility represents one of the original units organized in 1899 to form the American Smelting and Refining Company (later Asarco) (Hydrometrics, 1999a). The Facility operated for more than 100 years, until it was closed in April 2001.

The Facility was a custom smelter that processed ores and concentrates produced by individuals and companies other than Asarco. The smelter produced lead bullion from a variety of both domestic and foreign concentrates, ores, fluxes, byproducts, and other non-ferrous metal bearing materials (Hydrometrics, 1999a). Recovery of zinc from the smelter's waste slag was conducted at the Facility from 1927 to 1982 (EPA, 1989a).

The smelter operations at the Facility consisted of: (1) receiving feed stocks via railcar or truck; (2) various stages of mixing, blending, and proportioning; (3) making a roast (sinter); (4) smelting; and (5) final shipment of product to offsite locations. As part of the smelting process, several commercial byproducts of lead production were produced, including sulfuric acid and matte- and copper-enriched speiss. Slag was produced as a waste product of the smelting process (Hydrometrics, 1999a). A detailed discussion of former smelter operations at the Facility is included in Appendix 2-A, and a flow diagram of the process is provided in Appendix 2-B. The historical layout of the Facility is depicted in Figure 2-2 and in pdf format in Appendix 2-C.

2.3.2 Identified Onsite Sources/Source Characterization

Operations at the Facility dispersed metals into various media throughout the site and into surrounding areas, affecting human and livestock health, wildlife, and the environment. During the early to mid-1970s, the State of Montana began conducting investigations of smelter emissions and surface water discharges at the Facility. Findings from these early investigations confirmed that arsenic, lead, cadmium, and other contaminants were accumulating at high concentrations in the soil, surface water, and groundwater, and in street and household dust throughout the City of East Helena (METG, 2011a).

Historic onsite sources of contamination involved the smelter stack emissions; fugitive emissions from Facility operations, such as the blast furnace, dross plant, and sinter plant; ore storage area; slag pile; process ponds and process fluids circuitry; and direct discharges to Prickly Pear Creek and Wilson Ditch. These sources are summarized below based on information provided in previous documents (e.g., Hydrometrics, 2010a), and their locations are shown in Figure 2-2. In addition to the contamination associated with historic sources and operations, metals-contaminated soils act as an ongoing secondary source of groundwater contamination.

2.3.2.1 Speiss/Dross Area

The Speiss/Dross Area (including the speiss settling pond and speiss granulating pit) was used until 1991 for the speiss granulation process, in which speiss (a molten copper bearing material) was poured into the granulation pit and sprayed with cool water from the speiss

pond. The water then drained back to the pond to be recirculated during the next granulation cycle. Leakage of process fluids from the speiss pit and pond have been identified as a historic source of metals loading to groundwater.

2.3.2.2 Acid Plant Water Treatment Facility

The Acid Plant was used to produce food grade sulfuric acid. Before 1992, suspended sediments from the acid scrubbing process were settled in a concrete-lined settling pond and in-line settling tubs (dumpsters), and neutralized by lime application at the former acid reclaim facility. This water treatment system was identified as a source of process water leakage to groundwater.

2.3.2.3 Acid Plant Sediment Drying Area

From 1977 through 1991, sludge from the Acid Plant water treatment facility was stored on the Acid Plant sediment drying pad north of Upper Lake. This area was identified as a source of arsenic loading to groundwater.

2.3.2.4 Ore Storage Areas

Two primary ore storage areas were used during smelter operations: the Upper Ore Storage Area (located in close proximity to Upper Lake and Lower Lake) and the Lower Ore Storage Area (located on the southwest portion of the Facility). These areas contained stockpiles of ore and flux materials used in the smelting process, and also contained soil and construction debris stockpiles from historic plant operations. Stockpiling of materials in these areas was discontinued in 1989.

2.3.2.5 Slag Pile

Approximately 12 to 14 million tons of slag have been deposited at the Facility since operations began at the smelter. The slag pile contains both fumed slag (slag that was processed to remove residual zinc) and unfumed slag (not processed for zinc). Slag is an iron silicate residue or by-product of the smelting process. Although it contains elevated concentrations of lead and zinc, these constituents are primarily bound in the chemically inert iron/silicate slag matrix.

2.3.2.6 Process Water Circuit

Historically, the normal operating process circuit included four process water ponds that contained waters that were found to contain elevated metals concentrations. Potential leakage from the former process water circuit has been identified as a historic source of contaminant loading to groundwater. The four process water ponds include:

- Former Acid Plant settling pond (described above)
- Former speiss granulating pond and speiss pit (described above)
- Former Thornock Lake, an unlined process pond that was used to contain plant water and stormwater runoff before 1987, after which it was replaced with a steel tank (Thornock Tank) housed within a concrete vault. Sediments in the unlined former lake were impacted with metals.

- Lower Lake, which was used historically (until 1993) to store water from the main plant process circuit. As a result, water and sediments within Lower Lake were elevated in metals, leading to impacts to surrounding groundwater.

2.3.3 Overview of RCRA and CERCLA Actions

A chronology of significant EPA actions at the Facility under CERCLA and RCRA is provided in Table 2-1. The summary below is taken largely from information available on EPA and METG Web sites (EPA, 2011; METG, 2011a).

EPA proposed the Facility for listing on the National Priorities List (NPL) of Superfund sites in September 1983, based on findings of contaminated soils in City of East Helena residential areas, elevated metals levels in air, and contaminated process water ponds located over shallow groundwater at the Facility (EPA, 1989a). Field work for the EPA's Facility remedial investigation (RI) began in 1984, and the resulting RI studies on the possible effects of Facility contamination on soils, plants, livestock, and water resources were completed in 1987 (CH2M HILL, 1987a, 1987b, 1987c). Under CERCLA, the site was divided into five Operable Units (OU):

- OU1 - Process Ponds
- OU2 - Groundwater
- OU3 - Surface Soil, Surface Water, Vegetation, Livestock, Fish and Wildlife, Air (includes onsite soil, residential City of East Helena soils, limited Helena Valley soils, Prickly Pear Creek, Wilson Ditch, vegetation, cattle, fish, and waterfowl sub-units)
- OU4 - Slag Pile
- OU5 - Ore Storage Areas

EPA's Record of Decision (ROD; EPA, 1989a) for OU1 was issued in November 1989. As part of the ROD, the EPA selected the remedy to reduce groundwater pollution from the process ponds; the remedy included isolating the process waters from groundwater by constructing steel storage tanks and replacing leaking equipment, and removing contaminated soils and pond sediments. A 1990 Consent Decree between EPA and Asarco and Anaconda¹ Minerals Co. was reached regarding the removal of hazardous substances and reporting requirements for OU1.

In July 1991, Asarco began removal of contaminated soil from residential areas, parks, playgrounds, streets, and alleys in the City of East Helena (OU3). Much of the cleanup was completed by 1996. EPA deemed that the cleanup of residential soil in the Facility area is protective of human health, and the ROD for OU3 was issued in 2006.

While CERCLA was initially the governing authority for cleanup of residential and agricultural soils, and surface water or surface water sources, the Facility was regulated under RCRA while it was operating. In 1997, EPA initiated transfer of responsibility for

¹ In 1927, the Anaconda Company constructed a plant adjacent to the East Helena lead smelter for the purpose of recovering zinc from the smelter's waste slag. Asarco purchased this zinc plant in 1972, but operations were discontinued in 1982. This zinc plant was demolished in March 2005.

ongoing remedial activities at the Facility from its CERCLA program to its “corrective action” program under the RCRA. In January 1998, Asarco and EPA agreed to a multimillion dollar settlement for violations of RCRA and the federal Clean Water Act. The settlement also specified environmental management measures for the Facility, which was still an operating smelter at the time. A Consent Decree, effective May 5, 1998, initiated the RCRA corrective actions process. The May 1998 Consent Decree provided that the primary focus of further remedial investigation would be on contamination in groundwater, surface water, and soils, and in the former ore storage areas. Asarco closed the smelter in April 2001. Ongoing remediation of the Facility continues under EPA’s RCRA authority.

Asarco prepared the RCRA CC/RA report (Hydrometrics, 1999a) as part of the 1998 Consent Decree. Based on its review of the CC/RA report, EPA determined that interim remedial measures were necessary and warranted for portions of the Facility, and an Interim Measures Work Plan was prepared (Hydrometrics, 1999b). EPA also determined that an RFI was required for the Facility, with the RFI to be conducted in two phases. Phase I of the RFI was conducted in 2000 (ACI, 2005). Phase II of the RFI was initiated in 2010 (Hydrometrics, 2010a).

2.3.4 Summary of Previous Investigations

Several environmental studies have been conducted at the Facility following the early investigations that identified the smelter as a significant source of contamination to multiple media. Previous studies that are directly relevant to the Phase II RFI study (i.e., studies that evaluated contamination of onsite soils, sediment and/or surface water, or groundwater in the Facility vicinity) are listed in Table 2-2 and summarized below.

2.3.4.1 Remedial Investigation (RI) of Soils, Vegetation, and Livestock (CH2M HILL, 1987a)

The purpose of this study was to characterize the nature and extent of contamination in soil, vegetation, and livestock in the Helena Valley and to identify remedial action alternatives. The specific objectives with regard to soils were to determine whether metals concentrations in soils were elevated, to map the spatial distribution of soil metals relative to the Facility, and to evaluate the horizontal and vertical distribution of metals in soil and investigate soil properties that influence this distribution.

Soil samples were collected in June 1984 from a total of 157 sample locations in the project area. Samples were collected from surface/near-surface depths (depth of zero to 4 inches) at all locations and at deeper intervals (up to 30 inches deep) from 47 of the locations. The samples were analyzed for a full suite of metals. The locations of soil samples from the 1987 RI that are applicable to this Phase II RFI are shown in Exhibit 1, and the corresponding analytical results are included in the dataset evaluated in Section 6 of this Phase II RFI report.

2.3.4.2 Process Pond Remedial Investigation/Feasibility Study (RI/FS) (Hydrometrics and Hunter/ESE, 1989)

This study addressed the first OU assigned to an accelerated schedule set by EPA and Asarco, the Process Fluids unit (OU1; includes Process Ponds and Process Fluids Circuits sub-units). The Process Pond operable sub-unit consists of Lower Lake, the former speiss granulating pond and pit, the former Acid Plant water treatment facility, and former

Thornock Lake. The Process Pond RI/FS included a water-balance investigation of the main process-water circuit for Lower Lake and a physical characterization of each pond. Physical characterization included the sampling of sediment, soil, process water, and process fluids. The samples for the study were collected and analyzed during the period of November 1984 through May 1988. Ten bottom sediment samples were collected from Lower Lake and former Thornock Lake. Soil core samples (from boreholes drilled to depths up to approximately 40 feet below the ground surface [bgs]) were collected from 14 drill holes adjacent to the speiss granulating pond and the Acid Plant water treatment facility. The sediment and soil samples were analyzed for a full suite of metals. Sample locations for those sediment and soil samples collected as part of this study that are applicable to the Phase II RFI are shown in Exhibit 1, and the results are included in the datasets evaluated in Sections 9 and 6 of this Phase II RFI report.

2.3.4.3 Comprehensive RI/FS (Hydrometrics, 1990)

The *Comprehensive RI/FS* addressed the remaining OUs (OU2 through OU5), which were not included in the Process Pond RI/FS. The information presented in the *Comprehensive RI/FS* report includes data collected during the RI and information from previous water resources investigations (Phase I and Phase II monitoring). Sample collection efforts incorporated into the *Comprehensive RI/FS* that are relevant to this Phase II RFI study are summarized below.

The groundwater RI was conducted in three phases. Stratigraphic samples were collected from 63 soil core holes drilled in the study during the period from fall 1984 through fall/winter 1987. Of these drill holes, 43 were completed as monitoring wells and 8 were completed as piezometers. During the groundwater RI, 41 monitoring wells and 33 privately owned wells were sampled. The locations of the wells sampled during the groundwater RI are shown in Exhibit 1. Samples were collected on a bimonthly to semiannual basis (in accordance with the applicable work plans) during the period from fall 1984 through spring 1988. The samples were analyzed for selected metals in addition to conventional parameters. The 1984–1988 groundwater data are included in the dataset evaluated in Section 7 of this Phase II RFI report.

The surface soils portion of the RI had the following three primary objectives: (1) to determine metals concentrations within the immediate smelter plant area and in ore storage areas that had the potential to become wind-borne; (2) to more accurately map the spatial distribution of surface soil contaminants in the City of East Helena area; and (3) to determine the amount of contaminated surface soil that could enter the Prickly Pear Creek system during a storm event. In 1987, 26 potentially erodible surface soil samples were collected at the Facility and analyzed for selected metals. The locations of the surface soils samples collected during this RI that are applicable to the Phase II RFI are shown in Exhibit 1, and the analytical results for these samples are included in the dataset evaluated in Section 6 of this Phase II RFI report.

Samples for the surface water RI were collected during the Phase I Water Resources Monitoring (1984–1985) and Phase II Water Resources Monitoring (1986–1987) at 13 locations on Prickly Pear Creek, 3 locations on Wilson Ditch, in Upper Lake, at the diversion from the creek to Upper Lake, in a diversion culvert from Upper Lake to Prickly Pear Creek, 3 irrigation ditches, and at a seep located on the north side of the slag pile. Stormwater runoff from eight additional onsite locations was sampled following short, intense storm

events on June 29, 1985, and July 2, 1987. The 1984–1987 surface water sample locations were analyzed for selected metals and conventional parameters. The locations of the 1984–1987 surface water samples that are included in the dataset evaluated in the Phase II RFI are shown in Exhibit 1, and the results are included in the dataset evaluated in Section 8 of this Phase II RFI report.

In addition to evaluating contaminant characteristics of Facility surface water, the RI included investigation of surface water/groundwater interrelationships via continuous water-level recorders installed in monitoring wells located near Prickly Pear Creek and in the City of East Helena north of Highway 12. Surface water drainage at the Facility, in catchment basins, and offsite runoff areas were assessed to determine frequency of water retention and fate of runoff.

As part of the surface water RI, samples of bottom sediment were collected concurrently with the Phase I Water Resources Monitoring sampling event in November 1984 and during spring runoff in May 1985. The bottom samples were obtained from seven sites on Prickly Pear Creek, two sites on Wilson Ditch, and from Upper Lake. As part of the *Comprehensive RI/FS* activities, additional samples of bottom sediment and underlying strata (to a depth of 5 feet below creek bed surface) were collected in December 1985 at four locations in Wilson Ditch. The bottom sediment samples were analyzed for selected metals. The sampling locations for the bottom sediment samples that are applicable to the Phase II RFI are shown in Exhibit 1, and the results are evaluated in Section 9 of this Phase II RFI report.

2.3.4.4 Post-RI/FS Well and Surface Monitoring Report (Hydrometrics, 1995)

Groundwater and surface water monitoring data from nine biannual monitoring events (spring 1990 through spring 1994) are evaluated in the *Post-RI/FS Well and Surface Monitoring Report*. The report also presents and evaluates groundwater and surface water data collected on a more frequent basis during remediation of Lower Lake in 1994. The groundwater samples were collected from 55 groundwater monitoring wells. The surface water samples were collected in Lower Lake and at four locations in Prickly Pear Creek, including locations upstream and downstream of the smelter. The groundwater and surface water samples were analyzed for metals and conventional parameters. The monitoring well and surface water sampling locations are shown in Exhibit 1, and the relevant data are included in the datasets evaluated in Section 7 and Section 8 of this Phase II RFI report.

2.3.4.5 Metal Residues in Sediment and Biota from Prickly Pear Creek and Lake Helena (USFWS, 1997)

This study included evaluation of metals concentrations in Prickly Pear Creek sediment samples as part of the objective of determining trace element concentrations in sediment and biota upstream and downstream of the Facility. The sediment samples were collected in 1991 and 1992 and included eight locations at the Facility (three locations upstream from the smelter and five locations downstream of the smelter). The samples were analyzed for selected metals. The sample locations for this study that are relevant to this Phase II RFI report are shown in Exhibit 1 and the results are included in the dataset evaluated in Section 9 of this Phase II RFI report.

2.3.4.6 Final Plant Water Investigation Report (Hydrometrics, 1999c)

In response to a suspected leak in the Facility's underground water piping system, Asarco initiated an investigation of possible leakage effects on Facility groundwater in February 1998. Water-level data from monitoring wells located near and downgradient of recently abandoned pipelines were evaluated, and groundwater samples were collected for analysis of metals and conventional parameters. From one to six groundwater samples were collected from each of 13 groundwater monitoring locations between February and November 1998. The samples were analyzed for metals and conventional parameters. The groundwater sampling locations are shown in Exhibit 1, and the data are included in the dataset evaluated in Section 7 of this Phase II RFI report.

2.3.4.7 Current Conditions/Release Assessment (CC/RA) (Hydrometrics, 1999a)

The CC/RA was conducted in accordance with the 1998 RCRA Consent Decree. The purpose of the CC/RA was to assess the completeness and quality of the existing data that is to be used to define the nature and extent of contamination at or migrating from the Facility. The major objectives of the CC/RA were to:

- List all sources of existing data.
- Identify the availability of the data to EPA and address any issues related to data availability.
- Detail the nature and extent of each known or suspected release of hazardous waste, including associated migration pathways.
- Describe information regarding any existing interim corrective measures.
- Describe information regarding any final remedial actions.

The CC/RA evaluated onsite releases to groundwater, surface water, and soils for the geographic area encompassing the Facility and offsite areas affected by migration of contaminants from the Facility (except for air emissions). Because the focus of the CC/RA was on evaluation of existing data, no new samples were collected as part of development of the CC/RA report.

2.3.4.8 Supplemental Ecological Risk Assessment (EPA, 2005)

This study was conducted by EPA to address data gaps in the 1987 RI, including the need for additional information on metals concentrations in water bodies in the Facility vicinity (Lower Lake, Upper Lake, Prickly Pear Creek, and the Marsh area) and at reference sites outside the vicinity for comparison. The study used data collected by EPA in its 2003 field study for surface water, sediment, sediment toxicity, sediment porewater, benthic invertebrate tissue, benthic invertebrate community assemblage, fish tissue, and aquatic plants. These data include a total of 22 sediment samples, 13 sediment porewater samples, and 22 surface water samples collected at the Facility, at the locations shown in Exhibit 1. Although the focus of this study was a risk assessment for aquatic receptors, analytical results for metals concentrations in the 2003 surface water, sediment, and porewater samples are pertinent to the Phase II RFI and are included in the data evaluated in this Phase II RFI report.

2.3.4.9 2007/2008 Plant Site Demolition Soil Sampling Data (Asarco, 2008)

As part of ongoing Facility cleanup and demolition activities, and in accordance with the 1998 RCRA Consent Decree, soil samples were collected in September and October 2007, and in October 2008, from demolition footprint and exposed soil areas in the thaw house, main office, blast furnace baghouse, blast furnace flue, Monier flue, and Acid Plant stack areas of the Facility. The samples were analyzed for metals. The 2007/2008 demolition footprint/exposed area soil sampling locations are shown in Exhibit 1, and the results for these samples are included in the dataset evaluated in Section 6 of this Phase II RFI report.

2.3.4.10 2008 Interim Measures Groundwater Investigation

In coordination with EPA and MDEQ, and in accordance with the Interim Measures Work Plan Addendum (Asarco, 2008), Asarco conducted a supplemental groundwater investigation in 2008 that included installation and sampling of monitoring wells downgradient of the Facility. The objectives of the supplemental investigation were to:

- Determine the spatial extent of elevated groundwater selenium in the downgradient area north and west of the Facility.
- Determine the spatial extent of the low concentration groundwater arsenic plume north of the City of East Helena.
- Evaluate the slag pile as a potential source of elevated groundwater selenium.
- Supplement the existing monitoring well network west of the slag pile area.

In support of these objectives, four monitoring wells were installed at the Facility, and nine monitoring wells were installed downgradient of the Facility in the area north and west of the City of East Helena. The locations of the monitoring wells installed in 2008 are shown in Exhibit 1. Soil core samples were collected from the well borings at 2- to 5-foot intervals and analyzed for metals. The results for these soil samples are included in the dataset evaluated in Section 6 of this Phase II RFI report. Results for groundwater samples collected from these wells are included in the dataset evaluated in Section 7.

2.3.4.11 *Phase I RCRA Facility Investigation (RFI) Site Characterization Report East Helena Facility (ACI, 2005)*

The goal of the RFI is to investigate the remaining elements necessary to develop alternative corrective measures for the Facility that have not been addressed in previous investigations. During the *Phase I RFI*, surface soil sampling was conducted in the following areas:

- The former Lower Ore Storage Area in the western portion of the Facility (potentially impacted by ore and concentrate stored in the area before 1989)
- The former Upper Ore Storage Area in the area between Upper Lake and Lower Lake
- Tito Park (upland area in the southeast portion of the Facility, between Upper Lake and Lower Lake), which is potentially impacted from ore and concentrate stored in the area before 1989
- Rail corridor areas

- Miscellaneous unpaved areas within the Facility boundary
- Unpaved areas adjacent to the Facility

In 2001, 664 surface soil samples (up to depths of 36 inches bgs) from 111 sampling locations were collected and analyzed for selected metals. The *Phase I RFI* surface soil sampling locations are shown in Exhibit 1, and the corresponding analytical results are included in the dataset evaluated in Section 6 of this Phase II RFI report.

The *Phase I RFI* also included surface water data (1984 through 2002) from long-term post-RI/FS surface water monitoring in Prickly Pear Creek, Lower Lake, and Wilson Ditch to evaluate the effectiveness of corrective measures implemented on Lower Lake and to evaluate any effects to Prickly Pear Creek water quality. The surface water sample locations are shown in Exhibit 1 and the analytical data are evaluated in Section 8 of this Phase II RFI report.

As part of the *Phase I RFI*, subsurface soil samples were collected from 14 monitoring well borings, and groundwater samples were collected from the monitoring wells established at these locations in 2001. The locations of the monitoring wells installed in 2001 are shown in Exhibit 1, and the data are evaluated in Sections 6 and 7 of this Phase II RFI report.

2.3.4.12 Phase II RFI Site Characterization Work Plan, East Helena Facility (Hydrometrics, 2010a)

The *Phase II RFI Work Plan* addresses the site characterization portion of the Phase II RFI. As noted in the work plan, this represents a continuation of previous site characterization and evaluation programs, including the *Comprehensive RI/FS*, *CC/RA*, and *Phase I RFI*, and relies heavily on data and information obtained through those programs. The Phase II RFI site characterization includes a detailed review of existing Facility soils data, with the objective of delineating metals-impacted soils at the Facility and potential source areas for the groundwater plumes. The compilation and review of Facility soils data also provided the basis for design of the Phase II RFI field sampling program. No new samples were collected as part of the *Phase II RFI Work Plan* development.

2.3.4.13 Baseline Ecological Risk Assessment (BERA) (Gradient, 2010a, 2010b)

The BERA was designed to address specific data gaps with regard to determining the risk to ecological receptors in the Facility area from contaminated soil and sediment at the Facility. The BERA work plan (Gradient, 2010a) incorporated an Ecological Site Investigation, which included collecting data on metals concentrations from biotic media (including tissues from terrestrial and aquatic vertebrates and invertebrates) and abiotic media (including surface water, sediment, and soil) at the Facility. The targeted sampling areas included Prickly Pear Creek (upstream, downstream, and adjacent to the Facility), the Prickly Pear Creek riparian zone, Upper Lake, Upper Lake Marsh, Lower Lake, Tito Park, Wilson Ditch, and upland areas around the perimeter of the Facility. In 2010, 50 sediment samples, 35 surface soil samples, and 50 surface water samples were collected and analyzed for metals. Sample locations associated with the 2010 data collection for the Ecological Site Investigation are included in Exhibit 1. These data are included in the datasets evaluated in Sections 9, 6, and 8 of this Phase II RFI report.

2.3.5 Overview of Previous Remedial Actions

Remedial actions completed at the Facility under the CERCLA and Interim Measures programs have been described extensively in other documents (ACI, 2005; Hydrometrics, 1990, 2010a), and a detailed list of the remedial measures is provided in Appendix 2-A (Table 2-A-1). For the purposes of providing project background in this Phase II RFI report, the major remedial actions completed to date at the Facility and vicinity are listed in Table 2-3 and summarized briefly below. Areas associated with the remedial actions are depicted in Figure 2-3.

- *Residential soil removal:* In July 1991, Asarco began an offsite remediation project that resulted in removal of contaminated soil from more than 580 residences, 30 businesses, 2 public parks, 2 schools, and road aprons and alleys in the City of East Helena.
- *Onsite soil removal and sediment dredging:* Soil/sediment removals have occurred at Thornock Lake, Lower Lake, a portion of Wilson Ditch, the Upper and Lower Ore Storage areas, the Speiss-Dross Area, and the Acid Plant water treatment facility. Dredging of sediments from Lower Lake was completed in 1996.
- *Process water circuit / Stormwater treatment facility:* The Facility's process fluids circuit, a source of groundwater contamination, was addressed through a series of actions including the partial remediation of the Acid Plant and Speiss-Dross Area process water facilities in the late 1980s and early 1990s; modifications to the process water handling systems, including construction of two 1-million-gallon water storage tanks in 1990 that allowed cessation of process water discharges to Lower Lake; and eventual elimination of the process fluids circuit with closing of the plant. In addition, stormwater runoff now is collected and treated in the onsite water treatment facility (see Section 2.4.2) before being discharged into Lower Lake.
- *Pilot groundwater treatment:* In June 2005, a pilot-scale permeable reactive barrier wall was installed to treat arsenic in groundwater using zero-valent iron (ZVI).
- *CAMU I and II:* A Corrective Action Management Unit (CAMU) repository cell was constructed at the Facility in 2001 for the deposition of accumulated sediments and soils from implementation of OU1 remedial actions and other excavations. A second repository cell, CAMU II, was established at the site to contain demolition debris associated with Facility demolition activities.
- *Building demolition:* The smelter has been decommissioned and most of the former buildings and ore storage areas have been removed. All Facility demolition wastes have been placed in CAMU II.
- *Temporary caps:* Temporary caps (high-density polyethylene [HDPE] liners) have been constructed over most of the remediated areas at the Facility to reduce the potential for surface water (e.g., precipitation, snowmelt) to infiltrate through contaminated soils and leach contaminants to groundwater.

- *Slurry walls*: In addition to being covered with a temporary cap, metals-impacted soils in the Acid Plant sediment drying area and the Speiss-Dross Area were encapsulated within slurry walls in 2006 and 2007, respectively.

2.4 Current Facility Conditions

2.4.1 Facility Features

2.4.1.1 Slag Pile

The slag pile is approximately 60 to 80 feet high and contains an estimated 12 to 14 million tons of material that were deposited during the course of operations at the smelter. The slag pile currently covers approximately 35 acres (Hydrometrics, 2010a) and occupies the northeastern portion of the site (dark gray area shown in Figure 1-1).

2.4.1.2 Buildings and Temporary Caps

Most of the structures at the Facility have been demolished, contaminated soils have been excavated from beneath the former structure footprints based on post-demolition soil sampling data, and the demolition areas have been capped with temporary HDPE liners. The extent of the temporary HDPE caps that have been installed at the Facility are depicted in Figure 2-4.

2.4.1.3 Underground Utilities

As noted in the *Phase II RFI Work Plan* (Hydrometrics, 2010a), the distribution of former and remaining underground utilities that were associated with historic operations and structures at the Facility have the potential to influence site hydrology and groundwater contamination. As such, these features are factored into the hydrologic evaluation presented in this Phase II RFI report. Figure 2-5 shows the historic distribution of underground utilities and conduits beneath the Facility, and indicates which utilities/conduits have been removed, or backfilled/plugged as part of the Facility demolition.

2.4.1.4 CAMU I and CAMU II

The CAMU I repository cell contains more than 100,000 cubic yards of contaminated soil, sediment, and ore stockpiles that were removed from the Lower Ore Storage Area, the Upper Ore Storage Area, and the Tito Park area between Upper Lake and Lower Lake. As of the end of 2009, the CAMU II cell contained approximately 56,000 cubic yards (79,000 tons) of demolition debris related to the Facility's demolition activities (Hydrometrics, 2010a).

2.4.1.5 Slurry Walls

The configuration of the slurry walls surrounding the Acid Plant sediment drying area and the Speiss-Dross Area are shown in Figure 2-3.

2.4.1.6 Stormwater Treatment Facility / Process Water Circuit

The active stormwater treatment facility (also referred to as at the HDS [high-density sludge] Water Treatment Bldg) is located on the south side of the former ore storage building and treated effluent discharges to Lower Lake. Features associated with the former

process water circuit (i.e., the former Acid Plant settling pond, Speiss granulating pond and Speiss pit, Thornock Lake, and Lower Lake) are shown in Figure 2-2.

2.4.2 Environmental Permits/Licenses

Current operations at the Facility are regulated under two permits issued by the State of Montana and under the RCRA program managed by EPA. These permits are listed in Table 2-4 and briefly discussed below.

Stormwater treatment and discharge at the Facility are subject to the requirements of the two state permits. A three-phase HDS wastewater treatment system was installed at the Facility in 1994 and operates under an MDEQ wastewater discharge permit (Montana Pollutant Discharge Elimination System [MPDES] permit number MT-0030147; MDEQ, 2010a). The facility originally was installed to treat process and wastewater from the Facility, but now is used to treat only stormwater before discharge into Lower Lake. Stormwater runoff is stored in large tanks and then is processed by the wastewater treatment plant when needed. The HDS treatment system has a permitted discharge of 158,400 gallons per day (gpd) and a load-based permit for various metals (EPA et al., 2005). The Facility also holds an MDEQ-issued general permit for stormwater discharges to state waters (permit number MT-R000072).

Because the Facility falls under the federal requirements for facilities that treat, store, and/or dispose of regulated wastes, it is managed under EPA's oversight as part of the RCRA program (EPA identification number MT-D006230346).

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3 Environmental Setting

This section summarizes the environmental setting of the Facility area as it relates to identified sources, pathways, and areas of releases of hazardous constituents from the Facility. The descriptions provided in this section are, for the most part, distilled from documents previously prepared for the Facility (including CH2M HILL, 1987a; Hydrometrics, 2010a; and Gradient, 2010b) and provide generalized descriptions of information available in detail in other documents.

3.1 Physical Setting

3.1.1 Topography

The Facility is located in the Helena Valley, in the Northern Rocky Mountains physiographic province, between the Big Belt Mountains on the east and the Garnet Range on the west. The natural topography slopes gently to the north. The elevation near the center of the Facility is approximately 3,900 feet above mean sea level.

3.1.2 Climate

The climate of the Facility area is classified as modified continental, and is characterized by cold winters and moderate summertime temperatures. The average low temperature in January for the City of East Helena is about 8 degrees Fahrenheit (°F), and the average high temperature in July is about 85 °F (WRCC, 2011). The surrounding mountains generally shelter the Helena Valley from high winds. The predominant average annual wind direction and speed (measured at the Helena Regional Airport) is from west to east at approximately 7 miles per hour (mph).

Average annual precipitation measured at the City of East Helena for the 50-year period from 1961 through 2010 is 11.2 inches, with January having the lowest average monthly rainfall (0.45 inch) and June having the highest average monthly rainfall (2.0 inches) (PRISM, 2011). Most of the annual precipitation falls in April through July; for most of this period the precipitation typically occurs during showers or thunderstorms, but steady rainfall events are common in June. Average total snowfall for City of East Helena is about 40 inches, which occurs primarily during the period of November through March (WRCC, 2011).

Estimated evapotranspiration rates for the Facility area were based on information for the City of Helena (the closest location for which evapotranspiration data were available) for the purposes of input to the *Phase I RFI* groundwater flow model (ACI, 2005); these rates are 8.51 inches per year for paved areas and 9.57 inches per year for unpaved areas.

3.1.3 Surface Water Hydrology

Surface water bodies in the Facility area include Prickly Pear Creek, Upper Lake, Upper Lake Marsh, Wilson Ditch, and Lower Lake. These features are shown in Figure 2-1 and are described briefly below.

3.1.3.1 Prickly Pear Creek

The Facility lies within the Prickly Pear Creek watershed, which is part of the Missouri River basin. Prickly Pear Creek flows northward along the eastern and northeastern boundaries of the Facility from its headwaters in the Elkhorn and Boulder Mountains (about 30 miles south and west of the Facility). The water in Prickly Pear Creek eventually discharges into Lake Helena approximately 7 miles north of the Facility.

Base flow in Prickly Pear Creek is typically 25 to 30 cubic feet per second (cfs). Peak flows near the Facility during spring and early summer runoff have ranged from near 50 cfs to more than 300 cfs. Streamflow data from the creek indicate that rates of groundwater recharge to the creek (and loss from the creek to groundwater) are small in comparison to the overall streamflow.

Prickly Pear Creek has been a source of water for agriculture, mining, and industrial use for more than a century (ACI, 2005). From July through September, surface water is diverted from the creek for irrigation and during this time the creek often becomes nearly or completely dry. As noted in the *Comprehensive RI/FS* (Hydrometrics, 1990), Prickly Pear Creek has been affected by historical mining activities upstream of the Facility that have resulted in elevated concentrations of some metals in stream water and sediments upgradient from the Facility. Water quality in the creek is monitored regularly as part of the Facility's RI/FS monitoring program.

3.1.3.2 Upper Lake and Upper Lake Marsh

Upper Lake is located at the southern end of the Facility (hydrologically upgradient of the Facility). The open-water portion of Upper Lake covers approximately 20 acres, and depths in the lake range from 5 to 12 feet. The emergent marsh area associated with Upper Lake is covered with water ranging from a few inches to 2 feet deep. Upper Lake and Upper Lake Marsh are fed through diversion of flow from Prickly Pear Creek. Upper Lake discharges via return flow to the creek, seasonal discharge to Wilson Ditch, and through subsurface leakage, which comprises a significant source of recharge to the groundwater system underlying the Facility. Data from the *Comprehensive RI/FS* (Hydrometrics, 1990) showed that water quality in Upper Lake was essentially the same as Prickly Pear Creek upstream of the Facility.

3.1.3.3 Wilson Ditch

Wilson Ditch extends northwest from Upper Lake toward the Helena Valley and conveys water from Upper Lake to agricultural fields northwest of the site for irrigation and stock. Before 1997, Wilson Ditch crossed the Facility in a buried concrete pipe. In 1997, the original pipe was replaced with an underground HDPE pipeline relocated immediately south of the Facility (see Figure 1-1). The new ditch route eliminated the potential for water from the Facility to affect Wilson Ditch. Water flows in the ditch only during the irrigation season (approximately April through September). Measured flows in the ditch during those times are low, ranging from 1.46 to 8.26 cfs. Data collected in 2001 and 2002 for the *Phase I RFI* (ACI, 2005) showed that water quality in Wilson Ditch downstream of the Facility was the same as in upper Prickly Pear Creek.

3.1.3.4 Lower Lake

Lower Lake is a former process water pond located immediately north of Upper Lake. It covers approximately 7 acres and has a capacity of 11 million gallons (Hydrometrics and Hunter/ESE, 1989). The lake was created in the 1940s by constructing a berm across the northern portion of Upper Lake to separate process recirculation water from natural surface water in Upper Lake (ACI, 2005). Lower Lake receives recharge from precipitation, groundwater inflow, and treated stormwater from the Facility (authorized under MPDES Permit No. MT-0030147; see Section 2.4.2). There is no surface water discharge from Lower Lake. Discharge from Lower Lake occurs exclusively as seepage to the local groundwater system and as evaporation.

Seepage from Lower Lake has been identified as a historic source of metals loading to groundwater at the Facility and possibly to adjacent Prickly Pear Creek. As discussed in Section 2.3.5, Lower Lake was the focus of an extensive remediation program in the mid-1990s, including dredging of the lake sediments and placement of sediments in the CAMU I waste repository cell. Extensive water resources monitoring has been conducted in the vicinity of Lower Lake since at least 1985. The seasonal water resources monitoring generally has included collection of groundwater and surface water elevation data, streamflow monitoring in Prickly Pear Creek, and water quality sampling in Lower Lake, Prickly Pear Creek, and the intervening groundwater system. Review and interpretation of these data have been presented in previous documents, including the CC/RA report (Hydrometrics, 1999a) and the *Phase I RFI* report (ACI, 2005).

3.2 Ecological Resources

Habitats and species occurring in the Facility area are described in detail in the BERA report (Gradient, 2010b) and are briefly summarized in the following subsections. Additional detail is provided in excerpts from the BERA report that are included for reference in Appendix 3.

3.2.1 Terrestrial Habitats and Species

Terrestrial habitats in the Facility area include vegetated upland areas around the Facility perimeter, the sparsely vegetated area between Lower Lake and Upper Lake (referred to as Tito Park), and the riparian corridor along Prickly Pear Creek.

Terrestrial vegetation along the upstream portion of Prickly Pear Creek includes a variety of trees, shrubs, and grasses, with a moderately diverse assemblage of shrubs. Dominant vegetation along Prickly Pear Creek includes willows, sedges, grasses, and some trees. The wetland and marsh areas surrounding Upper Lake are dominated by willow (*Salix* spp.) and alder (*Alnus* spp.) stands, with some grasses in the drier areas, and cattails (*Typha* spp.) and reeds in the inundated areas. Forested wetlands in the southern portion of Upper Lake Marsh near the Prickly Pear Creek diversion include species such as aspen (*Populus tremuloides*), cottonwoods (*Populus deltoides*), and several grass species. The area around Lower Lake currently supports minimal vegetation, limited to some grasses, forbs, and shrubs. The Facility perimeter areas and Wilson Ditch are dominated by grasses, shrubs, and small patches of trees, including Russian olive (*Elaeagnus angustifolia*). A list of the dominant vegetation noted during site investigations is in the BERA report (Gradient, 2010b).

Terrestrial habitat along the Facility perimeter is limited to onsite areas near buildings, former operations and stockpile areas (including Tito Park, described below), and the open ranchland adjacent to the Facility (see Figure 2-1). These areas include notable human disturbance, but provide limited habitat for common species such as rabbits, squirrels, mice, and pigeons. The adjacent areas likely provide habitat for deer, small mammals, and upland game birds and predators (including red-tailed hawks, coyotes, and foxes), and support livestock (primarily cattle). On the eastern side of the Facility, terrestrial habitat features are similar to those observed near Prickly Pear Creek (i.e., vegetated with trees, shrubs and grasses, with vegetation becoming sparser with distance from the riparian zone). On the west side of the Facility, vegetation is predominately composed of grasses with a few other herbaceous plants and small patches of trees.

Tito Park, between Lower Lake and Upper Lake, is a disturbed, sparsely vegetated area that provides minimal upland habitat. The soils in this area are disturbed, and there is little cover for ecological receptors. Vegetation diversity in the Tito Park area is low, with grasses the predominant vegetation type. No trees are present in this heavily disturbed area. Tito Park has been the site of various Facility remedial activities, including removal of the Acid Plant sediments from the sediment drying pad in the extreme western portion of the area (1991/1992) and removal of additional stockpiled soil and debris piles (for placement in CAMU I) in 2001. These remedial areas are currently capped (see Figure 2-4).

The BERA report (Gradient, 2010b) identifies numerous terrestrial plant and invertebrate species and bird species that inhabit the Facility area, and lists several mammals that have been observed (or for which sign [e.g., tracks, scat] have been observed) in the area. The report also lists federally listed and state-listed endangered, threaten, proposed, and candidate terrestrial and aquatic plant and animal species that potentially occur in the Facility area, but notes that threatened and endangered species are not expected to occur at the Facility or in the surrounding areas (Gradient, 2010b; see Appendix 3 of this Phase II RFI report).

3.2.2 Aquatic Habitats and Species

Aquatic habitats in the Facility area include Prickly Pear Creek, Wilson Ditch, Upper Lake, Upper Lake Marsh, and Lower Lake. Aquatic habitat types identified within Prickly Pear Creek in the Facility area include runs, low gradient riffle, high-gradient riffle, scour middle artificial, damned main artificial, and bridge/dam outfall. The predominant bank cover type present along Prickly Pear Creek includes willow, sedges, grasses, trees, gravels, cobbles, and boulders. Substrates range from cobble-dominated material to sandy material.

The littoral zone bottom of Upper Lake Marsh is dominated by fine grained (silt, clay, muck) materials, with sparse to moderate quantities of sand and woody debris at some locations. Sparse or moderate to very heavy density fish cover is present in the forms of aquatic weeds, snags, brush or woody debris, and overhanging vegetation. Substrates and habitat characteristics are similar in Upper Lake itself. Fish habitat in Upper Lake includes both human and natural features consisting of covered areas composed of vegetated structures.

Lower Lake has a gravel and sand bottom, limited presence of shoreline and aquatic vegetation, and it appears to provide very poor aquatic habitat. Similarly, aquatic habitat in

Wilson Ditch does not support significant aquatic populations because it contains water only during the irrigation season.

Numerous aquatic plant species, benthic invertebrate species, and fish species occurring or potentially occurring in the Facility area are identified in the BERA report (Gradient, 2010b; see Appendix 3 of this Phase II RFI report).

3.3 Receptors

Human populations and environmental systems in the Facility area that are currently (or potentially in the future) affected by Facility-related contamination are considered potential receptors of interest for the human health and ecological risk assessment portions of the Phase II RFI. This section briefly characterizes the types of exposure pathways and the potentially affected human and ecological receptors that are factored into the risk assessments.

3.3.1 Human Health

Human receptor populations and exposure pathways for Facility-related contamination (via groundwater, sediment, surface water, and soils) include:

- Current and future workers involved with the environmental cleanup activities
- Trespassers onto the Facility
- Current and future residents and other people in surrounding areas that may contact windblown dust, surface water, or sediment derived from the Facility
- Current and potential future uses of potable and non-potable groundwater

These human receptor populations and related exposure pathways are briefly characterized below.

3.3.1.1 Receptors Via Surface Water Exposure Pathways

Users of surface water impacted by Facility contamination are susceptible to risk from exposure to metals if they come into contact with or ingest the surface water. Potential receptors in this category include:

- Agricultural workers using water from Prickly Pear Creek or Wilson Ditch
- Facility workers exposed to stormwater that is collected before treatment and discharge to Lower Lake
- Facility trespassers that come into contact with water bodies, such as Prickly Pear Creek or Lower Lake (note that trespass onto the Facility is restricted, with the intent of precluding excess exposure to non-workers)

3.3.1.2 Receptors Via Groundwater Exposure Pathways

The primary public drinking water source for the City of East Helena is surface water from McClellan Creek, obtained at a location approximately 5 miles south (upgradient) from the Facility. This source is not impacted or threatened by releases from the Facility. However, groundwater supplied from three municipal water wells located 1 to 3 miles north of the

City of East Helena serves as a secondary source of drinking water for the city. Municipal wells are used in the spring during runoff to mitigate turbidity problems in the primary surface water source, in the summer to supplement low surface water flows, and in the winter for freeze protection.

An unknown number of homes in the City of East Helena obtain domestic water from private wells located on the individual property. These are older wells; a City of East Helena ordinance enacted in September 2003 prohibits construction and use of new water supply wells within city limits.² Rural residents in the Helena Valley (including the outlying areas around the Cities of Helena and East Helena) rely solely on private wells for their water supply. Selected residential and public water supply wells are being sampled regularly as part of the ongoing groundwater monitoring program to ensure protection of groundwater users in these areas and to provide data to assist in defining the extent of Facility-related groundwater (METG, 2011b).

Other potential human receptors via groundwater exposure pathways are workers involved in the ongoing remediation work at the Facility who come into contact with, or inadvertently ingest, groundwater affected by Facility contamination.

3.3.1.3 Receptors Via Surface Soil Exposure Pathways

Site workers at the Facility may be exposed to metals in onsite surface soil through dust inhalation, ingestion, and direct contact; however, these risks are managed through an ongoing worker health and safety program managed in accordance with Occupational Safety and Health Administration (OSHA) requirements.

3.3.2 Ecological Receptors

Identification and evaluation of ecological receptor populations and exposure pathways have been a component of several previous investigations, including the 1987 RI (CH2M HILL, 1987a), *Comprehensive Endangerment Assessment* (Hunter ESE, 1989), *Comprehensive RI/FS* (Hydrometrics, 1990), *CC/RA* (Hydrometrics, 1999a), and *Supplemental Ecological Risk Assessment for the East Helena Smelter Site, Montana* (EPA, 2005). The recently completed BERA (Gradient, 2010b) provides a systematic evaluation of the likelihood and magnitude of unacceptable risks to ecological receptors posed by current or likely future exposure to metals in soil, water, sediments, plants, and biota at the Facility and its immediately surrounding areas. The BERA was designed to provide information required to support risk management decisions and to determine whether corrective measures are needed to protect ecological resources around the Facility.

The conceptual site model (CSM) that was developed as part of the BERA identifies and evaluates the following distinct ecological units (CSM units): Prickly Pear Creek, Upper Lake and Upper Lake Marsh, Lower Lake, Wilson Ditch, Tito Park, and the Site Perimeter. Representative ecological receptors of concern were identified for each of the CSM units to guide the risk assessment process. Ecological receptors identified at the Facility and examined in the BERA include benthic invertebrates, fish, amphibians, aquatic and terrestrial plants, soil invertebrates, birds, and mammals. Conclusions presented in the

² City of Helena Ordinance 227, 9-2-2003.

BERA report (Gradient, 2010b) with regard to the risk from Facility COPCs to ecological receptors in the CSM units are as follows:

- Prickly Pear Creek provides a range of habitats for aquatic and terrestrial receptors and is relatively undisturbed, except near the Facility. Current COPC concentrations in Prickly Pear Creek and associated riparian areas appear to pose minimal risks to the aquatic and terrestrial community. Further, onsite COPC concentrations are generally within the range of concentrations found in reference areas.
- The Upper Lake and Upper Lake Marsh area supports a diverse mix of habitats and ecological receptors. COPC concentrations are elevated in this area, particularly at the north side adjacent to Tito Park. Overall, risk estimates for this area were low to moderate.
- Risks to ecological receptors from metal exposures in Wilson Ditch are low to moderate. Metal contamination is evident in this channel and concentrations are similar to those of its primary water source, Upper Lake. However, Wilson Ditch provides limited habitat for aquatic receptors because water flows only during the irrigation season (approximately April – September).
- Lower Lake and Tito Park are manmade structures with minimal vegetation or habitat available for ecological receptors. Lower Lake and Tito Park have significantly elevated COPC concentrations in aquatic and terrestrial environments. COPC concentrations in these two CSM units posed a risk to most of the receptors evaluated in the BERA. In addition, Lower Lake is a likely source of COPCs to adjacent CSM units (i.e., Upper Lake and Prickly Pear Creek); additional corrective measures likely are needed to reduce the transport of COPCs to surrounding ecological habitats.
- The East and West Perimeters of the Facility are characterized by elevated metal concentrations indicative of impacts from historic smelting activities. The East and West Perimeter CSM units of the Facility have COPC concentrations that are elevated above reference areas and are expected to pose a risk to terrestrial ecological receptors. Overall, risks from soil exposures in these areas were characterized as high and remedial activities may need to be undertaken to reduce exposure.

The BERA concluded that the primary contaminants of concern (COC) for ecological receptors throughout most CSM units of the Facility are arsenic, cadmium, mercury, lead, and selenium. Other metals that may pose a risk in some areas closest to the Facility are antimony, manganese, silver, thallium, and zinc (Gradient, 2010b).

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4 Phase II RFI Approach

This section describes the objectives, scope, and technical approach to the Phase II RFI and additional investigations performed at the Facility in 2010. The detailed field testing and sampling methodologies are summarized in this section and presented in greater detail in Appendix 4-A. Sampling results, data analysis, and interpretation are presented in Sections 5 through 11.

4.1 Phase II RFI Objectives

The Phase II RFI was conducted in accordance with *the Phase II RFI Site Characterization Work Plan* (Hydrometrics, 2010a). The Phase II RFI is a continuation of the *Phase I RFI* initiated by Asarco in 1999 and is being completed by the Custodial Trust, under the direction of the EPA, as Lead Agency for the Facility, in consultation with the MDEQ. The objectives of the Phase II RFI characterization are to:

- Define the current nature and extent of Facility-related contaminants in onsite soil, groundwater, surface water, sediment, and stormwater.
- Identify source areas of the arsenic and selenium groundwater contaminant plumes.
- Collect data to support the evaluation of the fate and transport of arsenic and selenium in the subsurface, and the current status and predicted future behavior of the groundwater plumes.
- Collect data to better understand the geologic, hydrogeologic, hydrologic, and chemical characteristics of the Facility that control contaminant fate and transport in contaminated media (soil, groundwater, etc.).
- Provide information and data required for completion of the human health and ecological risk assessment portions of the Phase II RFI, and a RCRA CMS.

4.2 Summary of Phase II RFI Scope

The following sections provide summaries of the major Phase II RFI data collection activities. Details on sampling methodologies, sample handling, and analytical requirements are presented in the *Phase II RFI Site Characterization Work Plan* (Hydrometrics, 2010a); *Phase II RCRA Facility Investigation Field Sampling and Analysis Plan* (Hydrometrics, 2010b); *2010 Post-RI/FS Groundwater and Surface Water Field Sampling and Analysis Plan* (Hydrometrics, 2010c); and the 2010 stormwater sampling plan (Hydrometrics, 2010d). Appendix 4-A provides a description 2010 field sampling methodologies for surface soil, subsurface soil, surface water, and groundwater. Sediment sampling procedures are described in the BERA work plan (Gradient, 2010b). Results obtained from the Phase II RFI field sampling activities and maps showing 2010 sample locations are presented in Sections 6 through 10 of this document. Concurrent with the completion of the Phase II RFI, a

baseline ecological risk assessment (BERA) and a human health risk assessment (HHRA) are also being completed by the Custodial Trust.

Phase II RFI samples were submitted for laboratory analysis to Energy Laboratories in Helena, Montana. Energy Laboratories is certified by EPA Region 8 and the State of Montana under the Safe Drinking Water Act. Analytical methods and method detection limits are presented in the *Phase II RFI Work Plan*. Laboratory analyses were conducted in accordance with EPA-approved and/or industry standard analytical methods. Field parameters were measured by Hydrometrics' field technicians in accordance with applicable standard operating procedures (SOP) presented in the *Phase II RFI Quality Assurance Project Plan* (QAPP) (Hydrometrics, 2010e).

Quality control (QC) samples were collected for each sample media. Phase II RFI sampling results and QC data were reviewed by Linda L. Tangen, a third-party contractor, for quality and validated in accordance with the project work plan and QAPP. The validated data were entered into the project database and distributed to project stakeholders in accordance with the *Phase II RFI Data Management Plan* (Hydrometrics, 2010d). The analytical laboratory data sheets and tabulated analytical results are provided in this report as appendices and discussed in subsequent sections of this report by media.

4.2.1 Phase II RFI Surface Soil Sampling

Surface soil samples were collected in August 2010 at selected locations within and peripheral to the Facility. The Phase II surface soil locations included a subset of 19 sites previously sampled during the *Phase I RFI*, 9 Phase II monitoring well locations, and 20 soil boring locations, for a total of 48 sample sites. Phase II RFI surface soil sampling locations and results are presented in Section 6. The objectives of the Phase II RFI surface soil sampling program were to:

- Collect soil samples for analyses of an expanded list of metals (e.g., selenium) in previously sampled locations to determine if additional COPCs are present onsite.
- Provide an understanding of current soil contamination at the Facility site to support an evaluation of potential corrective measures.
- Provide concentrations of Facility contaminated media (e.g., soil, sediment, groundwater, surface water) for use in developing exposure point concentrations in the baseline ecological and human health risk assessments.

Based on these objectives, soil samples were collected from the zero to 6-inch, 6- to 30-inch, and 30- to 60-inch depth intervals at each of the 48 sampling locations. The zero to 6-inch and 6- to 30-inch depth intervals correspond in general to those previously sampled during the *Phase I RFI*, allowing for comparison of the Phase I and Phase II results. The zero to 6-inch depth interval samples also were used in the BERA, while the deeper samples were collected for evaluation of a construction worker scenario in the HHRA. In addition to the 48 sites sampled under the surface soil sampling program, an additional 31 surface soil samples (zero to 6-inch depth) were collected by Hydrometrics in support of the 2010 BERA. Results for these samples are reported separately in the BERA report (Gradient, 2010a) and are incorporated in the evaluation of soil contamination presented in Section 6. Deviations from the *Phase II RFI Work Plan* also are discussed in Section 6 and in Appendix 4-A.

4.2.2 Phase II RFI Subsurface Soil Sampling

Subsurface soil samples were collected and analyzed to meet the objectives of the Phase II RFI. For purposes of this report, subsurface soil samples are defined as those collected from greater than a 6-foot depth. Subsurface soil sampling was conducted at the same 20 soil borings and 9 monitoring wells discussed above. Phase II RFI subsurface soil sampling locations and results are presented in Section 6. Objectives of the subsurface soil sampling were to:

- Provide information on the distribution of metals in the subsurface soils.
- Evaluate relationships between subsurface soil concentrations and the arsenic and selenium groundwater plumes.
- Further define site geologic conditions beneath the Facility, particularly to determine the whether the low permeability volcanoclastic/fine-grained alluvium (i.e., silt/clay) is present beneath the Facility.

The subsurface soil sampling was conducted in accordance with the *Phase II RFI Work Plan*. Deviations from the work plan, caused by field conditions and/or opportunities to collect additional data or information, are described in Section 6 and in Appendix 4-A.

4.2.3 Soil Adsorption and Leach Testing

The *Phase II RFI Work Plan* and supporting information (Hydrometrics, 2010a; 2010h [see Appendix 6-I]) outline the adsorption and leach testing program for selenium and arsenic, using selected soil samples collected during installation of soil borings and monitoring wells. Testing of Facility soils during the *Phase I RFI* and previous investigations has provided data regarding arsenic leaching and adsorption behavior. However, site-specific data regarding potential sources of selenium to groundwater (historic process water releases, vadose zone soils, saturated zone soils, and/or slag) and mechanisms governing selenium fate and transport controls in groundwater (adsorption, precipitation) were limited. Therefore, a primary objective of the Phase II RFI testing program was to obtain leaching and adsorption data for selenium, with additional information on arsenic intended to supplement existing data. The objectives of the Phase II RFI soil adsorption/leach testing program were to:

- Evaluate whether soil in potential contaminant source areas will leach selenium and arsenic to groundwater.
- Assess the adsorption/desorption behavior of selenium and arsenic in different areas of the Facility, and the relationship of contaminant attenuation mechanisms to the configuration of the groundwater arsenic and selenium groundwater plumes.
- Support refinement of the CSM to support groundwater fate and transport modeling efforts for selenium and arsenic.

Soil samples for adsorption/leach testing were obtained from soil borings conducted in the Phase II RFI. Phase II RFI soil sampling locations selected for adsorption/leaching tests and results of the testing are presented in Section 6. Samples were selected for adsorption/leach testing based on total sample concentrations of arsenic and/or selenium; sample location

relative to current groundwater contaminant concentrations (i.e., location within the current arsenic and/or selenium groundwater plume); and specific program objectives.

Results of the adsorption and leaching tests are presented in Section 6 and evaluated in Section 11.

4.2.4 Monitoring Well Installations

Nine monitoring wells were installed as part of the Phase II RFI within the Facility boundaries and north/northwest of the Facility. Monitoring well locations are presented in Section 6. Subsurface samples were collected during monitoring well installation to characterize geologic conditions (see Section 5) and to collect soil samples for analytical testing as previously described. The objectives of the Phase II RFI well installations were to:

- Support further evaluation of horizontal and vertical groundwater flow at and near the Facility.
- Obtain additional geologic information to inform evaluation of subsurface data.
- Further delineate the lateral and vertical extent of arsenic and selenium contamination in groundwater.
- Identify potential source areas for the arsenic and selenium groundwater plumes.

The specific objectives of each well and variations from the *Phase II RFI Work Plan* are discussed in Appendix 4-A. Aquifer tests were conducted in each new well using pneumatic slug testing procedures to estimate aquifer transmissivity as described in the *Phase II RFI Work Plan*.

Water quality samples were collected from the Phase II RFI monitoring wells as part of the Post RI/FS Long-Term Monitoring Program (see below) conducted in October 2010. Samples were collected for physical parameters, common ions, and trace constituents (i.e., metals). Water quality results for the Phase II RFI monitoring wells are presented and discussed in Section 7 and are included in the project database.

4.2.5 Phase II RFI Groundwater/Surface Water Interaction Study

The *Phase II RFI Work Plan* (Hydrometrics, 2010a) identified understanding groundwater/surface water interactions (GWSWI) between the uppermost aquifer and Prickly Pear Creek as being of significance to quantifying groundwater flow and contaminant fate and transport in and around the Facility. Past synoptic streamflow monitoring on Prickly Pear Creek indicated decreased flows (caused by seepage) north of the Facility. The estimated difference in stream discharge between streamflow monitoring stations, located adjacent to the Facility, were within the level of error associated with streamflow measurements, resulting in limited information about GWSWI in the area. The evaluation of GWSWI in association with Prickly Pear Creek and the uppermost aquifer was designed to provide a detailed evaluation to better quantify the direction and rate of flow between the creek and groundwater. The objectives of the GWSWI evaluation were to:

- Quantify the direction and rate of flow between Prickly Pear Creek and the groundwater system adjacent to and north of the Facility.

- Identify areas of groundwater recharge, and potential contaminant transport, to Prickly Pear Creek.
- Evaluate the effect of seepage from Prickly Pear Creek on groundwater flow directions and plume migration directions.
- Provide information on leakage rates from Prickly Pear Creek to the shallow/intermediate aquifer (or vice versa) for use in setup and calibration of the numerical groundwater flow model discussed in Section 12.

The Phase II RFI GWSWI investigation included synoptic streamflow monitoring along the targeted segment of Prickly Pear Creek, surface water/groundwater level monitoring to quantify hydraulic gradients between the creek and the groundwater system, and installation of piezometers near the creek bank and installation of “mini-piezometers” within the active channel above the diversion dam located near Lower Lake. The methodologies used for the streamflow monitoring, groundwater level and surface water stage monitoring, and piezometer and “mini-piezometer” installation are described in the *Phase II RFI Work Plan*. Results of Phase II RFI GWSWI evaluation are presented and discussed in Sections 5, 7, 8, and 11.

4.2.6 Additional 2010 Monitoring Programs

The following sections summarize the scope of various groundwater monitoring programs conducted concurrently with the Phase II RFI at the Facility in 2010. These programs and the sampling locations comprising each program are identified in Table 4-1. The results of the programs are integrated into subsequent sections of this report.

4.2.6.1 2010 Post-RI/FS Groundwater and Surface Water Monitoring Program

This program, described in the *2010 Post-RI/FS Groundwater and Surface Water Monitoring Field Sampling and Analysis Plan* (Hydrometrics, 2010c), was conducted to meet the objectives of required Post-RI/FS monitoring and incorporates the groundwater monitoring requirements associated with the CAMU groundwater monitoring program (Hydrometrics, 2008), and the Acid Plant Sediment Drying (APSD) Area and Speiss/Dross Slurry Wall Operation and Maintenance Plans (Asarco, 2007a and 2007b).

Routine (semiannual) monitoring of groundwater and surface water within and adjacent to the Facility was initiated in 1985 as part of the RI/FS. Post-RI/FS (long-term) groundwater and surface water monitoring has been conducted at the Facility from 1991 to the present. This program consists of monitoring groundwater and surface water conditions (i.e., water quality and water levels) on a semiannual basis (usually May/June and October/November) at locations within and adjacent to the Facility. The data generated through this long-term monitoring program are used to evaluate long-term trends in groundwater and surface water quality and to characterize the status and evolution of groundwater contaminant plumes beneath and downgradient of the Facility. The emphasis of the program in 2010 was on arsenic and selenium migration, as well as delineation of plume source areas (Hydrometrics, 2010c). The objectives of the 2010 monitoring plan were to:

- Evaluate long-term groundwater quality trends.

- Characterize the status and evolution of groundwater contaminant plumes (particularly for arsenic and selenium).
- Identify groundwater plume source area(s).
- Satisfy the detection monitoring requirements associated with the Phase I and Phase II CAMUs.

Details regarding sampling locations, methodologies, and analytical requirements associated with the Post RI/FS Long-Term Monitoring and CAMU monitoring for 2010 are presented in the Post RI/FS work plan (Hydrometrics, 2010c). Data from this program are integrated into discussions presented in Sections 5, 7, 8, and 11 of this report.

4.2.6.2 Supplemental Groundwater Level Monitoring Program

This program was performed to obtain additional information on groundwater levels (i.e., elevations). The program included installation of transducers to obtain continuous (every 4 hours) groundwater level and temperature measurements in selected monitoring wells (see Sections 5 and 7). Transducer measurements were used to evaluate general water level trends upgradient, within, and downgradient of the Facility and within various potential hydrostratigraphic units. Seven wells were instrumented with transducers in April 2010. In addition, bimonthly manual water level measurements were collected from selected wells between April and August 2010, and monthly measurements were made between September and November 2010. Data from this program are discussed in Sections 5 and 7.

4.2.6.3 Groundwater/Surface Water Interaction Program

This program was conducted to support a detailed evaluation of GWSWIs between groundwater and Prickly Pear Creek adjacent to and north of the Facility. Monitoring was conducted at 11 wells, 11 piezometers, and 13 surface water sites (11 on Prickly Pear Creek, Lower Lake, and Upper Lake). Surface water stage and groundwater levels were monitored to quantify hydraulic gradients between the creek and the groundwater system. Groundwater monitoring was conducted in monitoring wells near Prickly Pear Creek and in shallow piezometers installed at various locations along the stream bank to assess groundwater levels and saturated conditions immediately adjacent to the creek. Two “mini-piezometers” (IP-102A/B and IP-103A/B), that are paired with surface water sites (PPC-102 and PPC-103), were installed/monitored in the active channel of Prickly Pear Creek adjacent to Lower Lake. The initial mini-piezometers (IP-102A, and IP-103A) were installed in the middle of the creek in late March 2010. At the time of installation the snow pack was low and high surface water flows were not expected to reach normal levels; however, spring snows and rains increased the snow pack, and subsequently surface water flows reached near flooding levels. The high surface water flows washed away the IP/PPC-103 and IP/PPC-102 monitoring stations in late May/early June. Replacement monitoring stations (IP/PPC-102B and IP/PPC-103B) were installed on July 22, 2010, near the western bank of the creek and re-instrumented with pressure transducers.

Wells APSD-7 and APSD-8; piezometers PZ-102, PZ-103, IP-102A/B, and IP-103A/B; and surface water sites PPC-102, and PPC-103 were instrumented with pressure transducers to collect water level data every 4 hours. Static water levels were collected at the 33 groundwater and surface water sites on a bi-weekly basis from April through August and

on a monthly basis from September to December 2010. Lake stage measurements were collected on a daily basis from April 7 to December 4, 2010.

Data from this program are integrated into discussions presented in Sections 5, 7, 8, and 11.

4.2.6.4 Southwest Lamping Field Groundwater Evaluation Program

In 2008, monitoring wells EH-128 and EH-132 were installed in the southwest corner of Lamping Field. The wells are located just east of Wilson Ditch and near the base of the tertiary sediment foothills flanking the Helena Valley. Elevated dissolved arsenic concentrations were detected in both wells. The Southwest Lamping Field Groundwater Evaluation Program was conducted to evaluate the source of the elevated arsenic concentrations in these wells. The program included groundwater level monitoring in wells in the vicinity, installation and monitoring of piezometers along Wilson Ditch, and synoptic streamflow survey on Wilson Ditch.

Groundwater level monitoring was conducted through the instrumentation of the two wells with pressure transducers on April 1, 2010, to monitor water levels every 4 hours, and manual static water level measurements as described in the programs above. The program was expanded on June 18, 2010, to include monitoring well EH-208 and a domestic well (no longer in use) at 2840 Winslow Avenue. These wells also were instrumented with transducers and included in the static water level monitoring schedule, described above. Additional wells to the southeast (SP-4, EH-205, and EH-210) and to the north (EH-134) were instrumented with transducers to monitor water levels in wells near Wilson Ditch that are upgradient and downgradient of wells EH-128 and EH-132. Testing of these new monitoring wells consisted of water quality monitoring and aquifer testing. Water quality monitoring was conducted as part of the Post RI/FS Long-Term Monitoring Program, which included measurement of static water levels, field parameters, and collection of water quality samples.

Data from this program are integrated into discussions presented in Sections 5, 7, 8, and 11.

4.3 Data Overview

Data collected from the 2010 Phase II RFI activities (and from the BERA and the additional monitoring programs described in Section 4.2.6 of this report) provide the foundation for the analyses and interpretations presented in this report. However, because the Phase II RFI represents a continuation of previous site characterization and evaluation programs performed at the Facility, most notably the *Comprehensive RI/FS*, *CC/RA*, and the *Phase I RFI* reports, data and information obtained through these previous programs and subsequent data collection efforts (such as the 2007–2008 plant demolition-related soil sampling and 2008 monitoring well drilling soils data) are incorporated into this report, as appropriate. Data collected outside of the *Phase II RFI Site Characterization* program are used in this report to aid in understanding and documenting current site conditions. This additional information includes:

- Soil, sediment, and surface water analytical results collected for the BERA.
- Groundwater and surface water analytical results collected under the Facility's Post-RI/FS Monitoring Program.

- Groundwater analytical results collected under the Facility's CAMU monitoring requirements.
- Results of a regional hydrologic evaluation aimed at determining potential connections between historic Facility operations and elevated arsenic detected in the nearby Seaver Park Subdivision.

After review and validation by the third-party contractor, the data collected as part of the Phase II RFI and other programs described above were entered into the primary project database, Envirodata 2008, and distributed to project stakeholders, as discussed in Section 4.1. The current database catalogues a variety of information for each sample, including sample type (soil, groundwater, surface water, sediment, process water, porewater, and surface water), analytical chemistry results, analytical methods, detection limits, sample coordinates, date of sample collection, water level measurements for selected monitoring wells, and other pertinent information. The third-party contractor also maintains a database of historic soil analytical data.

A compilation of available soil and water data from the project databases was presented in *Phase II RFI Site Characterization Work Plan* (Hydrometrics, 2010a). The soil data were divided into two groups: "Remediated Areas – Data No Longer Current" and "Non-Remediated Areas," which represent samples where soil has not been removed thorough past remediation activities and that therefore represent existing conditions. A map showing Phase II RFI sample locations and historic soil and water sampling locations is included as Exhibit 1. Remedial activities completed under the CERCLA and Interim Measures programs are summarized in Section 2 and Appendix 2-A.

4.3.1 Phase II RFI Data Use

Data collected from the 2010 Phase II RFI activities and other 2010 environmental investigation, together with applicable data and information obtained through previous programs (i.e., historic soil data from unremediated areas), form the basis of the information used in the Phase II RFI to evaluate the nature and extent metals-impacted soils and potential groundwater contaminant source areas. This information also will be used in the HHRA and in the groundwater flow and contaminant transport model.

Data from the Phase II RFI were combined with other recent and historic data to produce summary tables and figures depicting current contaminant concentrations in soil (see Section 6), groundwater (see Section 7 and 11), surface water (see Section 8), stormwater (see Section 10) and sediment (see Section 9). It is our understanding that current and historical data were collected in accordance with project-specific SOPs and MDEQ- and/or EPA-approved work plans under regulatory oversight, and were reviewed and validated by a third-party contractor. Therefore, current and historic data are assumed to be of acceptable quality for evaluating current site conditions.

4.3.2 Contaminants of Concern

For more than 100 years, lead and zinc smelting operations at the Facility deposited lead, arsenic, copper, zinc, cadmium, and other hazardous substances into onsite and offsite soil, surface water, sediment, and groundwater. Previous soil investigations have focused primarily on lead and arsenic because of risks posed to site workers and nearby residents. Previous groundwater investigations focused on arsenic as a primary COC based on its

presence in shallow groundwater downgradient of the Facility at concentrations exceeding levels considered safe for use as drinking water (maximum contaminant levels [MCL]). Selenium subsequently was identified as a primary COC in groundwater at the site based on concentrations detected above MCLs in downgradient, offsite wells. MCL criteria currently are exceeded in groundwater beneath the Facility at one or more locations for antimony, arsenic, cadmium, and selenium.

Previous investigations identified petroleum hydrocarbons (based on the visual observation of a hydrocarbon sheen or odor) in subsurface soil and groundwater onsite. The areas affected by hydrocarbon contamination are reported to have a limited extent on the Facility. Low or trace concentrations of organic constituents have been detected onsite. Organics have not been identified in previous investigations as a COC (ACI, 2005).

Groundwater exceeds federal Secondary Maximum Contaminant Levels (SMCL) for sulfate (250 mg/L), chloride (250 mg/L), and total dissolved solids (TDS) (500 mg/L), both onsite and downgradient of the site. SMCLs are guidelines established by EPA to "assist public water systems in managing their drinking water for aesthetic considerations" (EPA, 2011); a constituent is not considered to present a risk to human health at the SMCL. Sulfate and TDS are not considered COCs from a risk-based perspective, but are considered indicators of both historic Facility impacts to groundwater and of possible ongoing sources of contaminants to groundwater.

The Phase II RFI focused on arsenic and selenium, based on offsite concentrations exceeding primary MCLs. Sulfate was also included as an indicator of the migration of Site process waters and off-site exceedances of SMCLs.

4.3.3 Screening Levels

This section describes the screening level values (SLV) used in the Phase II RFI report to assess potential threats to human or ecological receptors that may come in contact with Facility contaminants in groundwater, surface water, soil, and/or sediments. SLVs used in this Phase II RFI report are presented in Table 4-2. Information supporting the selection of SLVs is presented in Appendix 4-B.

When a potentially complete contaminant migration pathway (to groundwater, surface water body, etc.) is identified, site-specific contaminant concentrations for each potential contaminant migration pathway (e.g., soil, stormwater, groundwater) are compared with appropriate SLVs. Contaminants detected concentrations exceeding an SLV will be considered site-specific COPCs in the affected medium for the purposes of this document. The distribution of COPC may be used to:

- Evaluate the adequacy of site characterization.
- Define areas exceeding SLVs for further evaluation including :
 - Completion of a human health or ecological risk assessment
 - Identification of the need for interim remedial actions
- Support risk management decisions including area where no further actions may be needed.

An exceedance of an SLV does not necessarily indicate the identified contamination poses an unacceptable risk to human or ecological receptors, but does trigger the requirement to evaluate the need for further investigation, risk assessment, and/or corrective measures.

The SLVs presented in Table 4-2 were chosen primarily to evaluate adverse impacts to groundwater receptors (i.e., domestic and public water supplies) and current and future occupants of the Facility. The SLVs were developed to conservatively identify potential threats to human health and the environment. It should be noted that the SLVs are not cleanup levels; they are comparisons used to establish priority for potential risk management activities or corrective measures. Some of the SLVs are below naturally occurring background levels for metals. Regional background concentrations are included in Table 4-2 and should be considered during site characterization, risk assessment, and when developing cleanup levels.

The SLVs selected for the *Phase II RFI Site Characterization* ("project SLVs") are described briefly below.

4.3.3.1 Groundwater SLVs

Groundwater in the vicinity of the Facility is used for both domestic and municipal purposes. Therefore, human health drinking water screening levels (MCLs) and EPA Regional tap water Preliminary Remediation Goals (PRG; EPA, 2010a) are included in Table 4-2. For each constituent, the project SLV for groundwater is the lowest of either the MCL or the tap water PRG.

4.3.3.2 Soil SLVs

Surface and subsurface soils may pose a risk to current or future site workers or occupants. Therefore, SLVs were selected primarily to be protective of human health. EPA Regional SLVs (EPA, 2010a) are developed to be protective of human health from direct contact and incidental ingestion of soil. The following EPA SLVs are included in Table 4-2 to evaluate metals concentrations detected in surface soil (defined as zero to 6 feet for the purposes of this report):

4.3.3.3 Industrial SLVs

- Residential Soil Screening Levels
- Protection of Groundwater Soil Screening Levels

For soil deeper than 6 feet, EPA's regional soil screening values were selected as project SLVs. These values were developed to protect groundwater quality from contaminants leaching from soil into groundwater at levels exceeding MCLs. Where these values were not available, EPA concentrations protective of tap water (set at a 1.0E-06 excess cancer risk) were used.

Direct evaluations of site-specific ecological risk are addressed in the BERA (Gradient, 2010a) and therefore are not considered in this document. Direct evaluations of site-specific risk to human health will be addressed in the HHRA, which is currently being developed.

4.3.3.4 Sediment SLVs

Project SLVs for sediment are based on protection of benthic invertebrates. Both the threshold effects concentration and the probable effects concentration identified in the BERA report (Gradient, 2010b) are presented in Table 4-2; for each constituent, the project SLV for sediment is the more protective of these two values.

4.3.3.5 Stormwater SLVs

Project SLVs for stormwater are based on screening levels for protection of groundwater; therefore the project stormwater SLVs and groundwater SLVs are the same.

4.3.3.6 Surface Water SLVs

Surface water project SLVs were based on Montana numeric water quality standards for human health from surface water (MDEQ, 2010) or protection of aquatic organisms as presented in the BERA report (Gradient, 2010b). The lowest of either the MDEQ human health surface water standard, the BERA surface water benchmark for chronic effects-total recoverable metals, or the chronic effects-dissolved metals was established as the project surface water SLV. The BERA surface water benchmarks for chronic effects-dissolved metals were consistently the more conservative screening values.

4.3.3.7 Regional Background Concentrations

The regional background concentration of selenium in groundwater was estimated using regional samples from the Montana Bureau of Mines and Geology (MBMG) and U.S. Geological Survey (USGS) data sets (USGS, 1992; MBMG, 2010) for the Helena Region to be approximately 0.006 mg/L (95th percent upper confidence limit [UCL] on the mean) (GSI, 2011). Literature reported background concentrations range between <0.001 mg/L and 0.008 mg/L, with an average concentration of 0.001 mg/L (USGS, 1992; MBMG, 2010). The analytical method reporting limit (MRL) for Facility groundwater samples have ranged from 0.001 mg/L to 0.005 mg/L. The selenium MRL is below the MCL of 0.05 mg/L.

The regional background concentration of arsenic in groundwater was estimated for the Helena Region to be approximately 0.017 mg/L (95th percent UCL on the mean) (GSI, 2011). Literature reported background concentrations range between <.001 and 0.037 mg/L, with an average concentration of 0.003 mg/L (USGS, 1992; MBMG, 2010). Arsenic background concentrations, while significantly lower than groundwater concentrations beneath and downgradient of the Facility, are near or above the MCL of 0.01 mg/L.

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5 Geology and Hydrogeology

This section summarizes the basic geologic and hydrogeologic setting of the Facility and provides an updated conceptual hydrogeologic model that incorporates findings from the Phase II RFI. The section is organized to provide an overview of the regional and local geology and hydrogeology, followed by a summary of previous investigations, and the Phase II RFI objectives related to better understanding the geologic and hydrogeologic conditions at the Facility. A description of the Phase II RFI findings and the conceptual hydrogeologic model for the site developed from a synthesis of recent and previous investigations complete the section.

5.1 Geologic and Hydrogeologic Setting

5.1.1 Geologic Setting

The Facility site is located at the southern end of the Helena Valley, a fault-bounded valley which is surrounded by uplifted folded and fractured sedimentary, metamorphic, and igneous bedrock of Precambrian to Cretaceous Age. The Helena Valley is filled with up to 6,000 feet of Oligocene (Tertiary) tuffaceous and alluvial strata, younger Tertiary alluvial gravel, and Quaternary alluvium and colluvium. Figure 5-1 is a geologic map of the Southern Helena Valley compiled by Reynolds and Brandt (2005). The Facility location is included for reference.

5.1.2 Stratigraphy/Hydrostratigraphy

The general sequence of regional stratigraphic units in the vicinity of the Facility consists of, from oldest to youngest in age:

- Metasedimentary basement rocks of the Middle Proterozoic Belt Super Group (e.g., Spokane Formation [Ys] and Greyson Formation [Yg])
- Early Tertiary (Oligocene) tuff, tuffaceous sediments, and intercalated alluvial sand and gravel (O_{Gts}/ O_{GS})
- Younger Tertiary alluvial gravel (mapped as older alluvium; Q_{tg})
- Quaternary alluvial sand and gravel (Q_a/Q_{al})
- Quaternary mixed alluvium/colluvium (Q_{ac})

The surficial distribution of these units is shown in Figure 5-1. Cross Section A – A' in Figure 5-2 is a north-south transect in the vicinity of the Facility and illustrates the thickness and distribution of these geologic units. Additional cross sections defining the geology underlying the Facility and its vicinity are included for reference in Appendix 5-A.

A brief summary description of each of these units and its hydrostratigraphic significance follows below.

Belt Supergroup Meta-Sediments (Spokane Formation): Metasedimentary rocks of the Spokane Formation are the bedrock base of the hydrostratigraphic system underlying the Facility and southern Helena Valley. These metasedimentary strata consist primarily of argillites, siltites, slates, and quartzites. These crystalline rocks have extremely low primary permeability except where extensively fractured (Thamke, 2000). For the purposes of this RFI, the upper contact of this unit with overlying sediments marks the base of the groundwater system.

Early Tertiary (Oligocene) Sediments: This unit consists of volcanoclastic and alluvial sediments (O_{Gts} / O_{Gs}) that overlie the Spokane Formation. These geologic materials generally form the uplands and foothills immediately adjacent to southern boundary of the Helena Valley, including the vicinity of the Facility (Figure 5-1). The thickness of the early Tertiary sediments in the vicinity of the site is interpreted to be 40 to 60 feet at the north end of the Facility and in the City of East Helena where it overlies Spokane Formation. The thickness of the sediments east and west of the Facility is not known; several wells penetrate 100 to 150 feet of the sediments without reaching the base. These strata consist predominantly of stratified volcanic tuff with thin, interbedded clastic sediments (Thamke, 2000; Reynolds and Brandt, 2005). Correspondingly, the hydrologic properties of this formation are highly variable. However, the formation in general is of relatively low permeability and groundwater flows from this unit and discharges to the higher permeability valley-fill sediments. The uppermost part of this unit is weathered, and commonly consists of a volcanic ash. Where present, the volcanic ash is generally weathered to a montmorillonite/bentonite clay. This is weathered ash deposit at the top of the early Tertiary sediments is important because, where present, it forms an aquitard that restricts groundwater movement between the Oligocene volcanoclastic sediments and the overlying alluvial sediments.

Younger Tertiary Alluvial Sediments (Qtg, Older Alluvium): The younger Tertiary sediments consist of weakly cemented sand and gravel derived from nearby uplands. Surface exposures of these sedimentary strata occur primarily in stream channels where erosion has exposed this unit.

The extent of the younger Tertiary alluvial unit in the sedimentary fill of the southern Helena Valley is not fully defined. However, this unit is present in many borings within the project area at thicknesses of between zero and 60 feet beneath the overlying Quaternary alluvial sediments. The Tertiary sediments are distinguished from the overlying Quaternary alluvium by a higher degree of cementation and higher silt content in the older alluvium. During drilling, the contact between the overlying Quaternary and the Tertiary sediments is difficult to discern because the units were deposited under similar conditions and appear similar in the drill cuttings.

Hydrologically, this unit contains varying degrees of cementation and thus likely overall has a lower permeability than the overlying, uncemented Quaternary alluvial deposits.

Quaternary Alluvial Deposits and Quaternary Alluvium and Colluvium: Quaternary strata is the uppermost geologic unit and comprises the surficial deposits found across the surface

of the Helena Valley, including the Facility. The Quaternary alluvial deposits consist of cobbles, gravels, and sand near stream channels and grades to finer sand, silt, and clay sediments with distance away from stream channels. Colluvial deposits interfinger with alluvium along the foothills west of the Facility and are composed of more angular and poorly sorted materials than the alluvial deposits because of the differences in deposition. The Quaternary sediments vary in thickness from a few feet to more than 60 feet thick beneath the middle portions of the southern Helena Valley. As described previously, the base of the Quaternary strata is generally interpreted in wells where uncemented strata (the Quaternary) overlie weakly indurated strata of the late Tertiary older alluvium, and by the presence of the weathered clayey ash at the top of the O₆ts unit. However, as discussed previously, this contact may be difficult to define during drilling.

The Quaternary strata is important to the Phase II RFI because it forms the primary shallow water-bearing interval in the Helena Valley. This groundwater is unconfined and displays varying degrees of hydraulic continuity depending on the nature of the materials at a particular location. The Quaternary deposits and underlying younger Tertiary sediments are postulated to behave as a single complex aquifer system on a regional scale (Briar and Madison, 1992) and are defined as the upper aquifer in this Phase II RFI.

5.1.3 Structural Geology

The southern side of the Helena Valley is defined by the Bald Butte fault zone, a major seismically active series of faults. The fault zone includes numerous subsidiary faults that bound the south side of the valley in the vicinity of the Facility, including one northwesterly trending fault inferred in Reynolds and Brandt (2005) to transect Lamping Field and East the City of Helena, north of the Facility (Figure 5-1). Generally, these subsidiary faults are normal displacement faults with the down-thrown side to the north. The older crystalline basement rocks and older Tertiary units that crop out in the foothills west of the Facility are not present in borings north of Lamping Field. The weathered clayey ash horizon at the top of the O₆ts unit transitions in the vicinity of the inferred fault trace to fine-grained alluvial sediments with reworked tuffaceous sediments from the O₆ts unit. One interpretation for this change and the absence of these older strata may be downward vertical displacement of the O₆ts to the north as a result of normal faulting and/or down warping. Figure 5-3 provides a schematic depiction of the relationships between geologic units in the vicinity of the Facility showing this interpretation.

5.1.4 Helena Valley Regional Groundwater Flow Characteristics

The Facility is located along the southern margin of the structural basin that forms the Helena Valley, and overlies the transition between the bedrock aquifers that bound the basin, and the valley-fill sediment aquifer system. The regional groundwater flow characteristics and relationships between the valley-fill and adjacent bedrock aquifer systems in the Helena Valley area have been most recently described in Briar and Madison (1992) and Thamke (2000). A potentiometric map of shallow groundwater levels by Briar and Madison (1992), provided in Appendix 5-B, illustrates the regional flow patterns in the basin and general relationships between groundwater and surface water. The general direction of groundwater flow within the valley and adjacent bedrock highlands is northerly toward Lake Helena, located approximately 7 miles north of the Facility site. Lake Helena is the regional discharge area for the Helena Valley aquifer systems.

The metasedimentary rocks and early Tertiary clastic alluvial and volcaniclastic sediments comprise the bedrock formations that bound the south side of the Helena Valley. The generally low permeabilities of the metasedimentary Spokane Formation, as well as overlying early Tertiary units are evidenced by high potentiometric gradients (Appendix 5-B).

Along stream courses, the Quaternary alluvial sediments are comprised of coarse sand and gravel mixtures with intercalated fine sediments and are highly transmissive. Poorly sorted and commonly silt-rich colluvium interfingers with alluvial sands and gravels along the basin margins. Farther toward the center of the basin and away from drainages, the percentage of fines increases. Although, intercalated silts and clays are estimated to comprise 30 to 70 percent of the upper several hundred feet of valley-fill sediments (Briar and Madison, 1992), water level and aquifer testing data indicate that the fine-grained layers are discontinuous and the upper portion of the valley-fill aquifer system is hydraulically connected.

Bedrock aquifers composed of the Spokane Formation and early Tertiary sediments in the Helena basin receive the bulk of recharge via snow melt, direct precipitation, and from surface water within losing reaches of streams. Groundwater migrating in these bedrock units eventually discharge to Lake Helena, local streams, springs and the valley-fill aquifer system. Upward groundwater flow from the bedrock aquifers into the overlying provides a significant recharge source to the uppermost aquifer. It has been estimated that upward groundwater flow from bedrock provides nearly 50 percent of the total annual recharge to the valley-fill sediments (Briar and Madison, 1992), comprising the largest single recharge source to the valley aquifer system. The remainder of recharge to the valley-fill aquifer systems includes snow melt, direct precipitation, irrigation canal losses, and deep percolation from irrigation and losses from creeks. Of these recharge sources, percolation from irrigation is considered the most significant source, while infiltration from snow melt and precipitation are estimated to provide minor contributions.

Major perennial streams in the basin include Ten Mile Creek and Prickly Pear Creek. These streams flow into the valley from the bedrock highlands and eventually discharge to Lake Helena. Both streams provide recharge to the valley-fill aquifer across the majority of the reaches between the highlands and Lake Helena. However, groundwater gradients transition from downward to upward flow conditions along a linear zone around Lake Helena (Briar and Madison, 1992). Across this zone, streams begin to gain from groundwater discharge as they approach the lake.

5.2 Previous Investigations

As described in Section 2.3.4, numerous environmental studies have been conducted at the Facility during the past 27 years. Although these efforts primarily were driven by the need to characterize the nature and extent of contamination, valuable information on the subsurface soil conditions, groundwater flow pathways, and GWSWIs can be obtained through examination of existing data. Several studies, including the CC/RA (Hydrometrics, 1999a), the *Phase I RFI* report (ACI, 2005), and the *Phase II RFI Work Plan* evaluated existing data and described the geologic setting and physical characteristics of the Facility. Relevant findings of previous investigations and ongoing monitoring at the Facility include:

- The majority of the Facility is underlain by a sand and gravel aquifer. The base of this uppermost aquifer is marked by a low permeability weathered tuffaceous sediment layer. The thickness of this upper sand and gravel unit increases to the north up to 50 feet near the northern boundary of the Facility. In previous investigations (ACI, 2005), the upper aquifer was divided into a shallow aquifer and deeper "intermediate" aquifer based on the presence of fine-grained lenses that restrict groundwater movement between upper and lower portions of the unit. However, based on further review of available information, including drilling of 15 additional wells in 2009, the shallow and deeper portions of the upper aquifer are believed to be in direct hydrologic communication, and, for the purposes of this Phase II RFI, are a single hydrologic system. Hydrostratigraphy of the Facility area is further discussed in Section 5.4.
- Groundwater at the site flows in a north to northwest direction from the Facility and fluctuates seasonally based on variations in recharge sources.
- Seepage from Upper Lake and Lower Lake provide a continuous recharge source to groundwater. Other significant sources of recharge include year-round seepage from Prickly Pear Creek north of the Facility and seasonal seepage from Wilson Ditch west of the Facility. Other sources of recharge include precipitation and groundwater inflow to the alluvial/colluvial aquifer from the surrounding foothills comprised of finer-grained tertiary sediments.

Historic soil boring and monitoring well logs are provided for reference in Appendix 5-C. Previous water level contour maps have been compiled in Appendix 5-D.

5.3 Phase II RFI Investigation

The Phase II RFI represents a continuation of previous site characterization and evaluation programs, most notably the *Comprehensive RI/FS*, *CC/RA*, and the *Phase I RFI*, and relies heavily on data and information obtained through those programs. The Phase II RFI included collection and analysis of surface and subsurface soil, sediment, groundwater, and surface water samples. The objectives, activities, and results that pertain to refining the hydrogeologic conceptual model are summarized in this section of the report and further discussed, by media, in Sections 6 through 10 of the document.

5.3.1 Phase II RFI Objectives

The general objectives of the Phase II RFI that pertain to the refining the hydrogeologic conceptual model include:

- Refine the understanding of groundwater flow in the project area in three dimensions.
- Delineate and characterize the nature and extent of the clayey weathered ash layer and equivalent that defines the base of the uppermost aquifer within the project area, particularly the northward extent.
- Evaluate the relationship between groundwater and Prickly Pear Creek adjacent to and north of the Facility, and Wilson Ditch, located west of the Facility, including

seepage rates, effects on groundwater flow and plume migration, and potential contaminant fluxes.

- Characterize groundwater contaminant distributions in three dimensions, particularly north and west of the Facility.
- Evaluate the source(s) of elevated arsenic in the southwest Lamping Field area.

Objectives specific to characterization are discussed, by sample media, in subsequent sections of this report. Activities key to refinement of the hydrogeologic conceptual model are summarized in Section 5.3.2.

5.3.2 Phase II RFI Activities

5.3.2.1 Soil Sampling and Monitoring Well Installation

Nineteen surface soil samples and 20 soil borings were conducted, and 9 monitoring wells were installed as part of the Phase II RFI within the Facility, and north/northwest of the Facility as shown in Exhibit 1 and Figure 5-4. While the primary objective of the surface soil sampling was to characterize contamination and risk, subsurface soil samples (collected at more than a 6-foot depth) provide information pertinent to the hydrogeologic conceptual model. In particular, the soil boring logs and analytical results help characterize the distribution of metals in subsurface soils and can be used in conjunction with groundwater data and the adsorption/leach testing results (Section 6.6) to evaluate contaminant fate and transport. Information obtained from the monitoring wells and soil borings was collected to evaluate three-dimensional (3-D) groundwater flow at the site, identify ongoing source areas for arsenic and selenium, delineate the 3-D plume configurations, and further delineate the top of the clayey weathered ash unit (base of the alluvial aquifer). The Phase II drilling photos, and test pit (surface soil), soil boring (subsurface soil), and monitoring well logs are included in Appendix 5-E. Sampling and analytical activities and additional documentation for soil and groundwater are discussed in Sections 6 and 7, respectively.

A memorandum summarizing the hydrogeology, based on review of the Phase II well logs, was prepared by Hydrometrics and is provided as Appendix 5-F. Observations made from the Phase II boring logs have been incorporated into the updated CSM discussion in Section 5.4.

5.3.2.2 Aquifer Testing

Aquifer tests were conducted using pneumatic slug testing procedures to estimate aquifer transmissivity at the new Phase II RFI monitoring wells. The pneumatic slug tests were conducted by depressing the water table by applying pressure to the well through the pneumatic slug apparatus. The well was instrumented with a pressure transducer to measure water levels as the well was pressurized. After water levels stabilized, the pressure was instantaneously released from the well and the pressure transducer recorded the water level rise. Three slug tests were conducted at each well to ensure reproducible results and provide accurate hydraulic properties.

A total of 21 pneumatic slug tests was performed on 7 monitoring wells. Slug test results were analyzed using AQTESOLV (v4.50) to calculate aquifer conductivity values based on the Bouwer and Rice Method (Bouwer and Rice, 1976) for damped water level responses

and the Springer and Gelhar Method (Springer and Gelhar, 1991) for under-damped responses. Additional information on aquifer testing methodology is provided in Appendix 4-A and the aquifer testing results are discussed in Section 5.4.

5.3.2.3 Groundwater Monitoring

Section 4.2.5 and 4.2.6 summarize the scope of various groundwater monitoring programs conducted concurrently with the Phase II RFI at the Facility in 2010. Groundwater quality sampling is discussed in Section 7 of this Phase II RFI report. In 2010, static water level measurements were collected at the groundwater monitoring locations shown in Figure 5-5 and Table 4-1. The largest concurrent water level measuring events took place as part of the June and October 2010 semiannual monitoring events. Static water level measurements were collected 1 or 2 days before the semiannual water quality sampling using an electric water level probe to determine the depth of groundwater below a specified measuring point (typically the top of the polyvinyl chloride [PVC] well casing). Measurement of static water levels (SWL) during the other monitoring events (see Sections 2 and 8) was conducted immediately before sampling the well. Field procedures for water level measurements are further discussed in Appendix 4-A.

Groundwater contour maps and a discussion of the Phase II water level monitoring results are incorporated into Section 5.4.

5.3.2.4 Groundwater/Surface Water Interaction Study

Groundwater and surface water level monitoring was conducted in 2010, under multiple programs: the GWSWI program, the supplemental groundwater level monitoring program, and the southwest Lamping Field groundwater evaluation program as discussed in Section 4.2.6.3. Piezometer logs are included in Appendix 5-E.

Results of Phase II RFI GWSWI evaluation are presented and discussed in Section 5.4 and Section 8 of this Phase II RFI report.

5.4 Updated Hydrogeologic Conceptual Model

5.4.1 Introduction

This section updates the hydrogeologic conceptual model for the Facility presented in the *Phase II RFI Work Plan* (Hydrometrics, 2010a). This updated conceptual model is based on recent data collected during the Phase II RFI by Hydrometrics, as well as the GSI Water Solutions, Inc. (GSI) review of the existing groundwater data (GSI, 2011). This updated hydrogeologic conceptual model provides a physical framework for Sections 6 through 11, which together comprise the CSM for the Facility.

The remainder of this section discusses, in order, the following elements of the hydrogeologic conceptual model:

- Site geology, including a detailed summary of the occurrence and nature of geologic units beneath the Facility and nearby environs, and geologic structure of potential relevance to groundwater occurrence and flow.
- Groundwater occurrence and flow, including definition of hydrostratigraphic units, including spatial distribution and hydraulic properties of the units; flow system

boundaries, including recharge/discharge; and groundwater levels, including gradients, and spatial and temporal variability.

5.4.2 Site Geology

This section summarizes the occurrence, distribution, and characteristics of geologic units within the project area. The surficial geology for the area is shown in Figure 5-1. Important features of the local geology include: the presence Spokane Formation metasedimentary basement rocks (Ys in Figure 5-1) nearby and beneath the Facility; the large area of alluvium (Qa in Figure 5-1) extending along Prickly Pear Creek from south of the Facility northward to the Helena Valley; the uplands or foothills comprised of Tertiary sediments (OgtS and OgS) south, east, and west of the Facility; and the intervening Qac deposits consisting of a mixture of alluvium and Tertiary sediments. In addition, a detailed summary of the distribution and nature of each of these units within the project area and key unknowns is provided in the remainder of this section. Some general inferred relationships between the units shown in Figure 5-1 are depicted schematically in Figure 5-3. Figures 5-2 and 5-6a through 5-6f are cross sections depicting the shallow stratigraphy beneath the project area based on logs of soil borings, monitoring wells, and private wells in the area.

Alluvium and Mixed Alluvium/Colluvium (Qa/Qac): The Facility is situated on recent unconsolidated alluvial/colluvial sediments that extent northward along Prickly Pear Creek and thicken in a northerly direction from the basin margins into the Helena Valley. The alluvium (Qa) represents relatively recent deposition of sediments from Prickly Pear Creek and forms in part the upper primary groundwater-bearing unit on and north of the Facility. The recent alluvium consists of generally clean sand and gravel with discontinuous silt/clay layers. Because of the low silt and clay content in the sand and gravel matrix, the recent alluvium generally has a relatively high permeability. The thickness of the alluvium typically ranges from 20 feet to more than 40 feet. The alluvium is overlain by a thin veneer of silt across much of the project area. Marsh/wetland sediments composed of 2 to 6 feet of organic-rich silt are present under the eastern portion of Tito Park and the southern portion of the slag pile. This organic silt layer terminates south of well DH-75 and north of soil boring RFI2SB-3, although several feet of soft sandy silt are described in borings underneath the remainder of the slag pile area.

Onsite and along the foothills surrounding the Facility, a heterogeneous mixture of alluvium and colluvium (Qac) exists and intervenes between early Tertiary volcanoclastic and alluvial sediments (OgtS and OgS) of the surrounding foothills. This transition from alluvium near Prickly Pear Creek to a mixture of alluvium and colluvium in the direction of the foothills is gradual and probably is best characterized as gradational and interfingering, as opposed to an abrupt change. The increase in fine sediment content with distance from the creek is evident from soil samples collected during monitoring well drilling in Lamping Field, and may influence groundwater flow in this area. This contact is further complicated by at least one fault, which is mapped northwest of the Facility (Figure 5-1). The offset along the mapped fault and presence of additional faults is poorly understood.

Quaternary/Tertiary Alluvium (Older Alluvium, Qtg): Older alluvium of early Quaternary and late Tertiary age underlies the more recent unconsolidated sand and gravel sequences. In the project area, these sediments are weakly consolidated sand, silty sand, and gravel with discontinuous silt layers (Section A - A"). The overall thickness of the unit in the

project area ranges from zero to 30 feet under the Facility, and increases significantly toward the north to more than 70 feet north of Lamping Field (Figure 5-6a, Section A – A’). West of the Facility, the unit occupies paleodrainages within older sediments and is more than 100 feet thick (Figure 5-6b, Section B – B’). Overall, the unit tends to include layers with a higher percentage of fines than the overlying alluvium. However, Briar and Madison (1992) indicate that the contact between the two units is not easily identifiable in driller’s logs, implying that the characteristics of the two units do not contrast significantly, although the older alluvium generally is inferred to contain more fines and cementation, diminishing the overall permeability of the sediments relative to the overlying Quaternary sediments.

Tertiary Volcaniclastic and Alluvial Sediments (O_gS and O_cS): These Oligocene-age sediments form the uplands or foothills south, east, and west of the Facility and consist of slightly to moderately consolidated volcaniclastic and alluvial sediments deposited by eruptive centers located south of the site and ancestral drainages. East of the Facility, the sediments are predominantly alluvial sediments with less volcaniclastic-derived materials (O_cS in Figure 5-1). South and west of the Facility (O_gS in Figure 5-1), the sediments consist of tan unconsolidated to weakly indurated siltstone and sandstone with varying amounts of volcanic ash and tuff beds partially or completely altered to clay. The weathered ash unit is believed to be concentrated in areas that were topographic depressions during the Tertiary, where eroded ash with varying amounts of clastic silt/sand would accumulate. The weathered interval appears to be most well developed on Tertiary strata that consist predominantly of tan silty to sandy sediments with varying amounts of volcanic ash and tuff beds altered to clay. As such, this weathered clayey ash horizon forms what is a low permeability layer at the top of the Oligocene unit and, where present, generally acts as an aquitard. Of particular interest in evaluating groundwater flow, contaminant migration, and potential corrective measures for the groundwater plumes is the continuity and nature of this clayey weathered tuffaceous layer beneath and north of the Facility.

Although few borings extend a significant depth within the Oligocene unit, the several explorations and private wells that do indicate that the nature of it varies vertically and laterally. Beneath the clayey weathered ash surface of the unit, borings encounter silt, sand and gravel with interbedded weathered ash horizons in the project area (cross sections B-B’, C-C’ and D-D’, Figures 5-6[b-d]). These clastic horizons within the unit are described in some boring logs as loose, saturated, water-producing intervals.

The vertical extent of the Oligocene volcaniclastic/alluvial sediments are not well defined as few monitoring well borings fully penetrate the unit. However, limited available information indicates that the thickness of the unit is variable. Boring logs of private wells located on the north side of the Facility and in the City of East Helena describe “Burnt shale” underlying the Oligocene age unit (Cross sections A-A’ and F-F’ in Figures 5-6 [a-f]). The burnt shale has been interpreted as argillite of the Spokane Formation, which would indicate that the Oligocene unit may only be 40 to 60 feet thick in these areas and is draped over underlying basement rocks. The unit is at least 100 feet thick in the Seaver Park area, as well as east of the Facility, across Prickly Pear Creek where a City of East Helena well (EH-2) penetrated more than 150 feet of the unit without reaching the base.

The unit does not appear to be present in wells located north of Lamping Field, on the north side of a normal fault that defines the contact of the Spokane Formation and Helena Valley-fill sediments northwest of the Facility (Figure 5-1). Boring logs show a transition from

volcaniclastic-dominated sediments to alluvium containing some reworked component of tuffaceous material north of Lamping Field. The Oligocene unit may be truncated and downdropped north of the inferred fault in this area, marking a transition from the Oligocene volcaniclastic unit to younger Tertiary alluvial sediments north of the fault. North of the fault, the Oligocene unit has been buried by later Tertiary alluvium containing reworked volcaniclastic sediments transported from the adjacent foothill exposures.

5.4.3 Site Hydrogeology Interpretation

Based on the stratigraphic information outlined above, several hydrostratigraphic units have been delineated in the project area. A hydrostratigraphic unit is one or more stratigraphic units with similar hydrologic characteristics allowing for grouping into a single unit for the purposes of describing groundwater occurrence and flow. The hydrostratigraphy forms the physical framework for groundwater flow and contaminant transport. Hydrostratigraphic units at and around the Facility are summarized in Table 5-1 and described here from top to bottom:

Upper Aquifer: The Upper Aquifer hydrostratigraphic unit is composed of unconsolidated granular fill, Quaternary alluvial/colluvial sediments and, where present, Quaternary/younger Tertiary alluvial sediments extending from ground surface down to the top of the clayey weathered ash surface of the Oligocene volcaniclastic sediments, where present. The granular fill includes regraded or placed earthen material (sand, gravel) and debris (slag, brick). The fill sits atop alluvial sediments (sand/silt/gravel) across most of the plant site, and atop clayey weathered ash surface on the west side of the plant. The Upper Aquifer pinches out where the Oligocene sediment surface daylights and the fill/alluvium ends in the foothills west of the Facility (Cross Sections B-B' and C-C' in Figures 5-6b and 5-6c).

On the east side of the Facility, the bottom of the Upper Aquifer is not defined. Alluvial sediments in this area increase in silt content and become denser with depth, signifying a transition to older alluvium. This older, alluvial material is noted on the cross sections as Quaternary/Tertiary Sand and Gravel and may correlate with the Qtg unit shown in Figure 5-1 and described above. As shown in Cross Sections B-B' and C-C', wells on the east plant site are not deep enough to determine if the clayey weathered ash surface exists under the slag pile or on the east side of Prickly Pear Creek adjacent to the Facility.

The Upper Aquifer hydrostratigraphic unit extends northward from Upper Lake, through the City of East Helena area and into the Helena Valley. Laterally, the Upper Aquifer unit extends to the east of Prickly Pear Creek, although losing reaches of the creek may act as a hydraulic divide in the Upper Aquifer unit northeast and north of the Facility. The western boundary of the unit is loosely defined as the Oligocene volcaniclastic and alluvial sediments that form the foothills west of the Facility.

North of the Facility (in the Lamping Field area), the Upper Aquifer includes a number of silt layers at depths of about 30 to 35 feet bgs. In previous reports, the Upper Aquifer was divided into separate shallow and intermediate aquifers based on the presence of intervening silt layers. Based on findings of the Phase II RFI, these silt lenses are not continuous and thus do not represent a competent confining layer. Therefore, the entire clastic sediment package above the ash/clay layer is now grouped as the Upper Aquifer and is considered a single, hydraulically connected and largely unconfined unit.

Oligocene (Tertiary) Clayey Weathered Ash Aquitard Unit: The clay-rich weathered ash surface of the Oligocene volcanoclastic sediments underlies the Upper Aquifer. This feature, where present, and the lateral equivalent fine-grained Tertiary alluvial sediments north of Lamping Field, form an aquitard unit. Figure 5-7 shows inferred contours of the Aquitard surface.

In some locations in the foothills southwest of the Facility, the Aquitard unit consists of tuffaceous sediments that are partially to completely altered in-place to white clay. The clayey weathered ash is believed to cover the western two-thirds of the plant site based on extrapolation of well log data, but its occurrence has not been confirmed on the northeastern portion of the site. On the plant site and in portions of the City of East Helena, the Aquitard unit occurs as distinctive white clay with quartz crystals and highly weathered feldspar grains. Farther north (including the Lamping Field area), the unit transitions to light brown to tan in color, contains a higher percentage of silt, and becomes less plastic (see Cross Section A-A," Figure 5-6a). As discussed in Section 5.2.3.1, this south-to-north change may be the result of the absence of the Oligocene volcanoclastic sediment unit caused by either truncation or downwarping, and lateral transition to fine-grained Tertiary basin-fill alluvial sediments, which include a component of reworked ash-derived clay eroded from the uplands to the south.

Based on extrapolation of well log data throughout the plant site, the City of East Helena and Lamping Field area, the Aquitard unit is present from south of the plant site northward through Lamping Field to monitoring well EH-139 (Figure 5-7). The depth to the Aquitard unit increases from about 20 feet bgs at the south end of the Facility, 50 feet bgs at the north end of the plant site, and 80 feet bgs at the north end of Lamping Field (monitoring well EH-130). Cross Section A-A" (Figure 5-6a) and Figure 5-7 show the depths to the unit as well as the elevation of the inferred surface.

Although the vast majority of monitoring wells do not penetrate through the weathered ash layer, a few wells do, providing limited information on the unit thickness and characteristics. Well DH-62 is located on the west plant site and encountered 25 feet of clayey weathered ash. From 55 to 77 feet, the layer transitions to a medium to fine sand with interbedded ash layers and some gravel. The well log for monitoring well DH-18 (central plant site) shows a generally similar sequence with clayey weathered ash layer encountered from 45 to 57 feet, transitioning to a sandier, saturated material from 57 to 68 feet. This general relationship of clayey weathered ash grading into a sandy water-bearing unit with interbedded ash has been observed at other wells, including DH-72 and EH-210, indicating the base of the Aquitard unit is gradational as opposed to abrupt. Wells DH-18 and DH-72 in Cross Section A-A" and well DH-62 in Cross Section B-B' are shown in Figures 5-6a and 5-6b.

Deeper Groundwater System: The Deeper Groundwater System hydrostratigraphic unit defines groundwater occurrence within older Tertiary volcanoclastic and alluvial sediments, and alluvial valley-fill sediments beneath the Aquitard unit, where present. As described above, deeper groundwater has been encountered beneath the Aquitard unit where there is a transition from tight clays to coarser-grained sediment intermixed with the weathered ash layer, which is evident at Facility monitoring wells DH-18, DH-62, and DH-72, and at well EH-210 located immediately west of the Facility (Figure 5-6). Coarse-grained Tertiary alluvial valley-fill sediments comprise the Deeper Groundwater System where Oligocene

volcaniclastics are not present, north of the Facility in Lamping Field and the City of East Helena.

Limited information is available regarding the Deeper Groundwater System although several wells associated with Facility cleanup activities have been recently installed or monitoring, and several private wells located peripheral to the Facility are completed within the unit.

Unlike the Upper Aquifer, which occurs as one continuous aquifer, the Deeper Groundwater System is interpreted to occur within multiple coarser-grained layers interspersed beneath the Aquitard. These deeper water-bearing zones are present within different materials at various depths. The presence and extent of the Deeper Groundwater System is not known because the vast majority of monitoring wells penetrate only the upper few feet of Aquitard, and the transition to the coarser-grained, water-bearing portion of the Oligocene volcaniclastic unit commonly occurs at least 10 feet or more below the top of the clayey weathered ash. Further, few wells north of Lamping Field are completed in valley-fill sediments below the interpreted Aquitard.

5.4.4 Groundwater Recharge

Sources of recharge to the Upper Aquifer unit include:

- Lower Lake and Upper Lake
- Prickly Pear Creek
- Seepage from irrigation canals/unnamed irrigation ditches
- Groundwater discharge from the Tertiary units that form the foothills on the southern and southwestern sides of the Facility
- Wilson Ditch, seasonally when operating
- Infiltration of precipitation and snowmelt
- Infiltration of irrigation water on agricultural lands

Areas of potential groundwater discharge from the Upper Aquifer unit include:

- Groundwater well extraction (domestic and public water supply wells, irrigation wells, etc.)
- Seepage to Prickly Pear Creek
- Seepage to Lake Helena
- Seepage to gravel ponds
- Evaporation from gravel ponds
- Springs

Water level (potentiometric) surface maps (Figures 5-8 and 5-9), for wells completed within the Upper Aquifer and Deeper Groundwater System show mounding and discharge to the Upper Aquifer from Upper Lake and Lower Lake. Mounding from losses to the Upper Aquifer unit from Prickly Pear Creek adjacent to and downstream of the slag pile also is apparent in both maps (Figures 5-8 and 5-9), though more apparent in June when higher

flows apparently result in greater losses to the Upper Aquifer. In June, mounding in the Upper Aquifer where Wilson Ditch daylighted from the pipe from Upper Lake also is readily apparent and exerts an influence on groundwater flow northwest of the Facility (Figure 5-8). The mounding from Wilson Ditch dissipates in the fall after the ditch is shut off, modifying equipotential and flow lines in the vicinity of the ditch (Figure 5-9).

Equipotential lines within the older Tertiary volcanoclastic sediments parallel the northwesterly trend of foothills that bound the west side of the Upper Aquifer. These equipotential lines define a steep gradient and flow from the older Tertiary sediments toward the Upper Aquifer (Figures 5-8 and 5-9).

Detailed discussion of the interactions between groundwater and surface water, including measured flux rates and variability in gradients near surface water, is provided in Section 8.

5.4.5 Groundwater Flow

5.4.5.1 Generalized Groundwater Flow Patterns

Groundwater flow in the Upper Aquifer through the Facility follows two general flow paths:

- Northerly from Upper Lake through Lower Lake and discharging to Prickly Pear Creek or continuing beneath the east side of the slag pile, and northward into the City of East Helena, where groundwater mounding from losses from Prickly Pear Creek creates an apparent groundwater flow divide and diverts groundwater flow lines in a northwesterly direction
- Northwesterly from Upper Lake through the former Acid Plant and Speiss-Dross Plant on the west side of the Facility. These general flow patterns continue north of the site Facility with groundwater flow primarily northward on the east side of Prickly Pear Creek and northwestward on the west side of the creek.

Flow from the downgradient (northwest) boundary of the Facility appears to be strongly influenced by several features, including:

- Groundwater mounding created by leakage from Prickly Pear Creek, which creates a flow divide at least as far north as Lamping Field (Figure 5-8).
- The presence of generally lower permeability Tertiary sediments with high northeasterly directed gradients bound the west side of the Upper Aquifer.
- The northwesterly orientation of a buried channel incised into the clayey weathered ash layer of the Aquitard unit (Figures 5-5 and 5-8). This erosional feature is believed to represent an ancestral channel of Prickly Pear Creek and may influence groundwater flow at the base of the Upper Aquifer in areas between the Facility and Lamping Field.
- The high permeability of the Upper Aquifer material within the ancestral channel likely contributes to the elongate shape of the groundwater contaminant plumes.
- Seasonal groundwater mounding near Wilson Ditch further diverts groundwater flow in the Upper Aquifer unit into the northwesterly trending flow axis into Lamping Field (Figure 5-8). The arsenic and selenium groundwater plumes in this

area closely correlate with this northwesterly flow direction and with the erosional trough (or paleo-channel) in the top of the Aquitard unit. Mounding from Wilson Ditch and Prickly Pear Creek dissipates in the fall, modifying the flow direction in Lamping Field to more northerly.

5.4.5.2 Groundwater Levels and Seasonal Fluctuations

During the Phase II RFI, groundwater levels were measured in selected monitoring wells with continuous recording transducers. Seasonal fluctuations ranging from 2 to 12 feet were observed in 2010. The seasonal high groundwater level was observed to occur between August and September and the seasonal low was observed to occur between May and June. Groundwater level fluctuations were least for the one Deeper Groundwater System unit well (DH-18) and wells located at the Facility, whereas wells completed in the Upper Aquifer unit offsite typically showed greater fluctuations, possibly the result of the significant, but seasonal, groundwater recharge that occurs from Wilson Ditch losses and Prickly Pear Creek streamflows.

Transducer data for wells outside the areas directly influenced by stream losses show peak water levels in August, after the snowmelt runoff and peak precipitation months of June and July, and during irrigation season. Wells near losing reaches of Prickly Pear Creek show rising water levels beginning in April and peaking in June, coincident with the peak streamflow period. Water levels in wells near Wilson Ditch are highly sensitive to flows in the ditch. A response to irrigation flows in the ditch was observed in wells completed in the Upper Aquifer, and in well EH-210, which is completed in the Oligocene volcanics of the Deeper Groundwater System. The rapid response in EH-210 indicates that a direct connection exists between Wilson Ditch and the Deeper Groundwater System, suggesting either that the Aquitard is not present, or that the ditch is excavated through the Aquitard in this area. Compiled water level data and hydrographs for select wells are provided in Appendix 5-H.

5.4.5.3 Groundwater Gradients

Horizontal hydraulic gradients vary from east to west and from north to south through the project area. Horizontal gradients calculated for the *Phase II RFI Work Plan* (Hydrometrics, 2010a) are summarized below.

- On the plant site, horizontal gradients range from 0.017 foot/foot (ft/ft) on the east side of the Facility, to 0.025 ft/ft on the west side of the Facility based on the November 2008 potentiometric surface (Figure 5-9).
- North of the plant site, gradients range from 0.014 ft/ft east of Prickly Pear Creek, to 0.012 ft/ft west of the creek.

Vertical gradients calculated from 2008 and 2009 monitoring data are shown in Figure 5-10 and summarized as follows:

- Vertical gradients are primarily oriented downward in the Upper Aquifer unit, indicating a downward component of groundwater flow. The largest downward gradient occurs in well pair EH-52/EH-102, north of the plant site and east of Prickly Pear Creek (approximately 0.12 ft/ft). Vertical gradients at other well pairs are typically on the order of 0.01 ft/ft or less.

- The vertical gradient at plant site wells DH-13 and DH-18, the only well pair completed in the Upper Aquifer and Deeper Groundwater System and monitored at that time, was upward in both November 2008 (+0.061 ft/ft) and May 2009 (+0.082 ft/ft).

Additional well pairs were installed and/or monitored as part of the Phase II RFI field program; these wells are shown in Figure 5-10. Vertical gradients calculated from 2010 monitoring are shown in Table 5-2 and Figure 5-11. Hydrographs of well pairs showing seasonal trends in gradients are shown in Figures 5-12 [a-c].

5.4.5.4 Hydraulic Conductivities

Aquifer testing has been conducted at the Facility as part of previous investigations and the Phase II RFI Site Characterization to evaluate hydraulic properties of the aquifer underlying the Facility. Pumping test and slug test results, including well completion data, test duration, analyses types, and test results are summarized in Appendix 5-G.

For the Phase II RFI, 21 pneumatic slug tests were performed on 7 new monitoring wells. The lowest conductivities were found in the Deeper Groundwater System, ranging from 3 to 11 feet/day (ft/day), while deeper Upper Aquifer wells (31 to 58 ft/day) generally had higher conductivity values than the Upper Aquifer (15 to 34 ft/day) wells. Results from the Phase II RFI testing fall within the range of parameter values derived from prior investigations and are provided in Table 5-3.

Hydraulic conductivity values calculated from testing of the shallow and deeper intervals of the Upper Aquifer unit range from approximately 10 ft/day to 700 ft/day. Storage coefficient values derived from all pumping tests ranged from 0.05 to 0.0001. The long-term pumping test at well TW-1 yielded hydraulic conductivity values from 7 to 123 ft/day and storage coefficient values ranged from 0.011 to 0.025. Hydraulic conductivities calculated from slug tests ranged from 2 to 365 ft/day.

Significant differences are evident in the aquifer parameters, with test results showing order of magnitude differences within relatively short distances (ACI, 2005). These differences may be caused by the presence of highly heterogeneous conditions, differences in scale of observation in comparing different types of tests imposing varying stresses, or ambiguous data. The highest hydraulic conductivity values occur in the west plant site area, which includes the former Acid Plant and Speiss-Dross source areas. The west plant site area also exhibits the greatest horizontal hydraulic gradients, meaning groundwater flow rates are greatest as well. The higher groundwater flow rate may be related to an ancestral channel of Prickly Pear Creek extending northwest through the west plant site.

5.4.5.5 Groundwater Flow Velocities

Hydrometrics (2010a) estimated groundwater flow rates for various portions of the Facility. The apparent groundwater velocity (specific discharge) is calculated as the product of the hydraulic gradient times the hydraulic conductivity, while the average linear velocity, or velocity of an actual water particle in the aquifer equals the apparent velocity divided by the effective porosity. The groundwater flux, or volume of flow per time, is equal to the apparent groundwater velocity times the aquifer cross sectional area (width times saturated depth).

The groundwater velocities and flux rates within the Upper Aquifer have been estimated by Hydrometrics (2010a) for the east plant site, west plant site, east downgradient area, and west downgradient areas using data from previous investigations. More recent estimates have not been derived using Phase II RFI data. Hydrometrics' 2010 estimates, based on average parameters, are provided in Table 5-4.

As shown in Table 5-4, although estimated groundwater flow velocities decrease down gradient from the Facility, overall groundwater flux rates increase significantly. Decreased velocities reflect greatly increased saturated thickness of the Upper Aquifer, whereas greater overall fluxes likely accommodate significant recharge to the groundwater system from groundwater inflow from the surrounding (and possibly the underlying) Tertiary sediments (e.g., Deeper Groundwater System), and leakage from Prickly Pear Creek.

6 Soil

6.1 Summary of Previous Investigations

Previous soil investigations at the Facility included sampling for metals. The results found that surface and subsurface soils have elevated metals, with arsenic, cadmium, copper, lead, and zinc having the highest concentrations. Of the metals found in soil, arsenic³ was identified as the most mobile in the subsurface environment, by leaching and transport in groundwater. The locations with the highest metals concentrations detected in soil samples from previous investigations at the Facility include:

- The former Acid Plant sediment drying pads
- The former Acid Plant water treatment settling facility
- The former Speiss Settling pond and Speiss granulation pit (Speiss Handling Area)
- The Lower Ore Storage Yard
- The area between Upper Lake and Lower Lake

These source areas are shown in Figure 6-1. Historic soil sampling locations are shown in Figure 6-2, and a compilation of existing soil sampling data collected at these locations is provided in Appendix 6-A. Figure 6-2 also includes the 2010 sample locations from Phase II RFI activities.⁴ Exhibit 1 shows current and historic sample locations.

In the early and mid-1990s, soil from selected area was excavated from identified source areas and placed in stockpiles on the property. These former soil stockpiles contained elevated arsenic and other metals. The former soil stockpiles (shown in Figure 2-3) were located in the following areas:

1. Stockpiles between Upper Lake and Lower Lake (Tito Park) (estimated 17,000 cubic yards)
2. Shew Ridge stockpile, along the western boundary of the Facility (estimated 35,000 cubic yards)
3. Lower Lake sediment stockpile, in the Lower Ore Storage Yard (27,000 cubic yards)
4. Lower Ore Storage Yard stockpile (24,000 cubic yards)

The soil and sediment in the stockpiles were excavated as part of CERCLA remedial actions or as part of other construction-related activities. The testing conducted in 1999 and 2000 as

³ Selenium was not identified a contaminant of concern until 2008.

⁴ A figure showing only historic sample locations can be found in the *Phase I RFI* (Exhibit 1 Historical and Existing Monitoring Sites).

part of Interim Measure investigations indicated that concentrations of metals in the stockpiled soils did not pass the Toxic Characteristic Leaching Procedure (TCLP) criteria for disposal as solid waste. Based on the TCLP results from the stockpile samples, in 2001, the soils were removed and permanently placed in an onsite CAMU repository cell. It is important to note that the chemical concentrations in these soils are representative of former source areas and are not representative of current site conditions.

A significant volume of slag is stockpiled at the Facility. Slag is a by-product of the lead-smelting process and contains elevated concentrations of metals. Previous studies concluded the leachability of slag was low under natural conditions because of its amorphous (vitrified or glassy) crystalline texture. The *Comprehensive RI/FS* (Hydrometrics, 1990) and *CC/RA* (Hydrometrics, 1999a) examined potential impacts to groundwater and surface water from the slag. These evaluations concluded there was little evidence for transport of arsenic and metals from the slag pile, with the possible exception of direct erosion of the slag material itself during infrequent high streamflow events in Prickly Pear Creek, which is adjacent to the slag pile area. Additional evaluation of the slag pile area that was conducted as part of the Phase II RFI and is discussed in Section 6.2 of this Phase II RFI report.

Information from the two major previous investigations evaluating contaminant concentrations in Facility soils is summarized below. Additional background information on these investigations (*CC/RA* and *Phase I RFI*) is presented in Section 2.3.4.

6.1.1 Historical Soil Conditions during 1999 Current Conditions/Release Assessment

The *CC/RA* (Hydrometrics, 1999a) summarized current soil conditions at the plant based on existing information available at the time of the report. The nature and extent of contamination in the ore storage areas, including surface soils, stockpiles, and slag, were presented. A copy of the existing soil data evaluation from the *CC/RA* is provided in Appendix 6-B. A complete listing of all sources of data that were used in the *CC/RA* soils analysis (originally presented in Appendix 3-1-1 of the *CC/RA*⁵) also is included in Appendix 6-B.

These resources provide an indication of the historical nature and extent of soil contamination, but do not necessarily represent current soil conditions at the Facility. The summary of soil conditions presented in the *CC/RA* (see Appendix 6-B) was updated in 2005 during the *Phase I RFI*, as described in the next section.

⁵ The *CC/RA* Appendix 3-1-1 also describes the available data, publication dates, data location, level of data validation, and a listing of all available reports and documents relating to the collection and interpretation of the data such as work plans, quality assurance plans, sampling plans, validation reports, construction reports, construction documents (plans and specifications), project reports, and EPA responses. Soil sample results are presented in Appendix 3-1-3 of the *CC/RA*. Exhibit 3-2-1 in the *CC/RA* shows the location of historical monitoring sites within the study area.

6.1.2 Historical Soil Conditions During 2005 Phase I RFI

As a part of the *Phase I RFI* activities, 664 soil samples were collected at 111 locations. Soil sample depths ranged from zero to 14 feet (typically 3 to 6 feet) bgs. The soil samples were analyzed for total metals. Selected samples also were analyzed using the Synthetic Precipitation Leachate Procedure (SPLP) to determine leachability of metals under natural (rainfall and snowmelt) conditions. Appendix 2 of the *Phase I RFI* Report (ACI, 2005) contains the surface soil data results and soil descriptions. Summary statistics for soil sample results (originally presented in Tables 2-3-1 through 2-3-6 of the *Phase I RFI*) are included in Appendix 6-B.

Metals concentrations in the *Phase I RFI* soils samples typically were elevated relative to background values. Of the metals analyzed, arsenic, cadmium, copper, lead, and zinc had the highest concentrations. The highest concentrations of arsenic, cadmium, and lead were from samples collected in former Acid Plant sediment dewatering/storage areas (near the former Upper Ore Storage Area). The former Upper Ore Storage Area and railroad track corridors also had elevated concentrations of arsenic and other metals in soil profile samples.

Soil arsenic and metal concentrations were generally higher in near-surface soils and typically decreased with depth. Exceptions to this general trend were observed in the former Upper Ore Storage Area, where arsenic and metal concentrations were high throughout the depth of the soil profile (typically 3 to 6 feet).

Results of SPLP analyses showed arsenic leachate concentrations were less than the 5.0 milligrams/liter (mg/L) Federal criteria⁶ for defining hazardous waste, with the highest test result for arsenic being 0.22 mg/L⁷. Additionally, five test results from samples from rail corridor areas showed cadmium leachate concentrations above toxicity criteria for defining hazardous water (1.0 mg/L), with the highest concentration being 9.8 mg/L.

Groundwater modeling results conducted for the *Phase I RFI* suggested the potential for groundwater quality impacts from leaching of surface soils to be low, with only minor groundwater arsenic concentration increases (0.01 to 0.3 mg/L) predicted within a limited area in the central west site area. Leaching of contaminants from soil to groundwater also was reported to have a low potential for contaminating groundwater, based on the low infiltration rates of surface water into Facility soil and slag. In addition, the suspension of dust control water application in conjunction with Facility closing just before the Phase I sampling activities were reported to reduce the potential for leaching. As a result, surface soils were not identified in previous investigations as a significant source of arsenic concentrations in groundwater, particularly if infiltration of surface water is controlled (ACI, 2005).

⁶ Federal criteria for hazardous waste are based on the TCLP used to define characteristic wastes under 40 CFR Part 261 Subpart C.

⁷ This concentration exceeds EPA's MCL for arsenic in public drinking water supplies.

6.2 Phase II Investigation

As outlined in the *Phase II RFI Work Plan* (Hydrometrics, 2010a), soil samples were collected in August 2010 at selected locations within and peripheral to the Facility. The Phase II RFI soil locations included a subset of sites previously sampled during the *Phase I RFI* in addition to Phase II RFI monitoring well and soil boring locations. Phase II soil sampling locations are shown in Figure 6-3 and are described in Tables 6-1 and 6-2. Additional soil sampling was conducted for the 2010 BERA (Gradient, 2010a). The following sections present the results for the 2010 Phase II RFI soil sampling and the results of 2010 BERA soil sampling program.

6.2.1 Phase II Soil Sampling Methodology

The surface soil sampling methodology was conducted as specified in the project *Phase II RFI Field Sampling and Analysis Plan* (Hydrometrics, 2010c) and the project *Quality Assurance Project Plan* (QAPP; Hydrometrics, 2010e). Phase II RFI field sampling procedures are described in Appendix 4-A.

Phase II RFI surface soil sample locations were photographed and coordinates recorded using a resource-grade global positioning system (GPS) unit. Supporting project data are provided in report appendices, including laboratory results (Appendix 6-C), boring logs (Appendix 5-E), field sampling notes (Appendix 6-D), photographs (Appendix 6-D), and survey information, which has been reviewed, validated, and entered into the project database.

Soil samples were submitted to Energy Laboratories in Helena, Montana, for analyses of metals, organics, and pH as shown in Table 6-2. The resulting data were reviewed by a third party contractor for quality and validated in accordance with the project work plan and QAPP. The validated data were entered into the project database and distributed to project stakeholders per the *Phase II RFI Data Management Plan* (Hydrometrics, 2010f). The 2010 soil results are summarized in Appendix 6-D and are discussed in the following sections of this report.

6.2.2 Phase II RFI Surface Soil Sampling

The Phase II RFI surface soil samples (defined for the purposes of this report as samples from depths of 5.0 feet and shallower) were collected in August 2010 at selected locations within and peripheral to the Facility. A total of 48 surface soil locations were investigated and included the following:

- Composite samples collected from test pits at a subset of sites previously sampled during the *Phase I RFI* (19 sites)
- Soil samples collected from Phase II RFI monitoring well borings (8 sites)
- Soil samples collected from Phase II RFI soil boring locations (21 sites)

These soil sampling locations are shown in Figure 6-3, and are described in Table 6-1. In addition to the 48 sites sampled under the surface soil sampling program, an additional 31 surface soil samples were collected in support of the 2010 BERA (Gradient, 2010a).

Objectives of the Phase II RFI surface soil sampling program included providing:

- Soil chemistry data from a subset of previously sampled locations to provide data for an expanded list of metals
- Current information on shallow soil conditions at the site for evaluation of appropriate corrective measures
- Information for use in the ecological and human health risk assessments

Based on these objectives, surface soil samples were collected from the zero to 0.5-foot, 0.5 to 2.5-foot, and 2.5- to 5-foot depth intervals at each of the 48 sampling locations. The zero to 0.5-foot, and 0.5- to 2.5-foot depth intervals correspond in general to those previously sampled during the *Phase I RFI*, allowing for comparison of the Phase I and Phase II results. The zero to 0.5-foot interval samples correspond to intervals sampled in the 2010 BERA, and the 0.5- to 2.5-foot samples were collected to evaluate exposure scenarios in the HHRA.

6.2.2.1 Test Pits Sites

Surface soil samples were collected from backhoe test pits at 19 of the 48 Phase II RFI sampling sites. At each of these sites, the test pit was excavated to a depth of 5 feet and soil samples collected as composite samples from the specified depth intervals. The zero to 0.5-foot and 0.5- to 2.5-foot interval samples were obtained by collecting a subsample at the specified interval from each of the four pit walls, and compositing the four subsamples into a single composite sample. The 2.5- to 5-foot interval samples were collected from soil piles excavated from this depth and stockpiled separately by the backhoe from the shallower excavated soils. Test pit logs are presented in Appendix 5-E.

6.2.2.2 Soil Boring/Monitoring Well Sites

Surface soil samples were collected at 29 of the Phase II RFI drilling locations, including 21 soil boring sites and 8 monitoring well sites. Sampling intervals at all soil boring/monitoring well locations were to those described above for the test pit sites; zero to 0.5-foot, 0.5- to 2.5-foot, and 2.5- to 5-foot depth intervals as shown in Table 6-2. Soil sampling deeper than 5 feet is discussed below under Subsurface Soil Sampling, Section 6.2.3.

Specific objectives of the Phase II RFI surface and subsurface data collection for each of the boring locations as stated in the work plan are as follows:

Lower Lake Soil Boring (RFI2SB-1):

- Investigate arsenic and selenium in soils as potential sources of the eastern Facility groundwater selenium plume (extending from beneath the slag pile to north of the Facility) and low concentration arsenic plume (extending from Tito Park northward beneath the slag pile).
- Investigate the potential for seepage from Lower Lake to adjacent Prickly Pear Creek.
- Provide subsurface soil data for expanded list of metals.

- Determine depth to the weathered clayey ash unit (base of Upper Aquifer).

Tito Park Soil Borings (RFI2SB-2, RFI2SB-3, RFI2SB-22):

- Further characterize soils between Upper Lake and Lower Lake, where prior sampling has shown elevated arsenic concentrations in unsaturated and saturated zone soils.
- Obtain selenium concentration data in unsaturated and saturated zone soils upgradient of documented selenium plume.
- Provide subsurface soil data for expanded list of metals.
- Determine depth to weathered clayey ash unit (base of Upper Aquifer).

Acid Plant/Monier Flue/Blast Furnace Flue Soil Borings (RFI2SB-4, RFI2SB-5, RFI2SB-6, RFI2SB-18):

- Further define unsaturated and saturated zone arsenic and selenium soil concentrations in an identified arsenic source area, and near the upgradient end of the west Facility selenium plume.
- Evaluate vertical extent of identified elevated concentrations of soil selenium in former Monier Flue footprint.
- Provide subsurface soil data for expanded list of metals.
- Determine depth to weathered clayey ash unit (base of Upper Aquifer).

Central Plant Soil Borings (RFI2SB-7, RFI2SB-8):

- Assess current soil chemistry in saturated and unsaturated zone soils within primary groundwater arsenic plume, to evaluate potential ongoing arsenic loading to groundwater through desorption (or other release mechanisms) from historically affected soils.
- Measure selenium soil concentrations (and forms) in reduced groundwater zone, to evaluate potential formation of reduced forms of selenium (elemental selenium or selenides) as sinks for removal of selenium from groundwater.
- Provide subsurface soil data for expanded list of metals.
- Determine depth to weathered clayey ash unit (base of Upper Aquifer).

Western Plant Area Soil Borings (RFI2SB-9, RFI2SB-10):

- Evaluate soil selenium concentrations near the western selenium plume centroid (area of highest groundwater selenium concentration) to determine if soils are acting as ongoing sources of selenium to groundwater.

- Provide subsurface soil data for expanded list of metals.
- Determine depth to the weathered clayey ash unit (base of Upper Aquifer).

West of Facility (RFI2SB-11):

- Assess current soil chemistry in saturated and unsaturated zone soils between Facility and railcar staging area.
- Provide subsurface soil data for expanded list of metals.
- Determine depth to the weathered clayey ash unit (base of Upper Aquifer).

Former Zinc Plant Soil Borings (RFI2SB-12, RFI2SB-13, RFI2SB-14, RFI2SB-15):

- Assess current soil chemistry in saturated and unsaturated zone soils at former zinc plant and along western edge of slag pile.
- Provide subsurface soil data for expanded list of metals.
- Determine depth to the weathered clayey ash unit (base of Upper Aquifer).

Between Ore Storage Building and Former Zinc Plant (RFI2SB-16, RFI2SB-17):

- Assess current soil chemistry in saturated and unsaturated zone soils between the ore storage building and former zinc plant.
- Provide subsurface soil data for expanded list of metals (and BTEX if any visual staining or petroleum odor is noted in soils).
- Determine depth to the weathered clayey ash unit (base of Upper Aquifer).

Former Thornock Lake (RFI2SB-19):

- Assess current soil chemistry in saturated and unsaturated zone soils within footprint of former Thornock Lake process pond.
- Provide subsurface soil data for expanded list of metals.
- Determine depth to the weathered clayey ash unit (base of Upper Aquifer).

Former Administration Building (RFI2SB-20):

- Assess current soil chemistry in saturated and unsaturated zone soils within footprint of former Admin Building.
- Provide subsurface soil data for expanded list of metals.
- Determine depth to the weathered clayey ash unit (base of Upper Aquifer).

Northern Facility(RFI2SB-21):

- Assess current soil chemistry in saturated and unsaturated zone soils in vicinity of pilot PRB.
- Provide subsurface soil data for expanded list of metals.
- Determine depth to the weathered clayey ash unit (base of Upper Aquifer).

6.2.2.3 Deviations from the *Phase II RFI Work Plan* for Surface Soils

Several sites identified for surface soil sampling in the *Phase II RFI Work Plan* were eliminated from the program for various reasons. These include:

6.2.2.3.1 Test Pits

- **Rail Car Staging Area locations RCSA-2, RCSA-5, and RCSA-8:** These sites are located west of the Facility and off METG property. The sites were eliminated from the program with the consent of the regulatory agencies because of delays in obtaining access agreements from the property owner and the data were determined to be unnecessary for purposes of the BERA.
- **Unpaved Facility Area location UPS-SS-5:** This site is located next to the former Sample Crushing Mill building, which was demolished in 2009. Extensive soil sampling was conducted in this area following demolition of the mill, with samples tested for a full suite of parameters including selenium. Because of the availability of existing soils data from this area, the site was eliminated from the Phase II RFI sampling program with agency approval.
- **Thornock Lake site TL-003:** This site is located near former Thornock Lake. Surface soil sampling was deemed unnecessary by the agencies because soils were excavated to depths of about 10 feet and replaced with clean fill at that time.
- **Acid Facility SS-28:** This site is located near the former Acid Plant, and near Phase II soil boring RFI2SB-18. The site was eliminated from the program with agency consent because of the proximity to SB-18 (and associated soil sampling at SB-18).
- **Onsite Rail Corridor site RC-SS-22:** This site was eliminated from the program with agency consent because of its proximity to soil boring RFI2SB-8 (and associated soil sampling at SB-8).

6.2.2.3.2 Soil Borings

- **Soil Boring RFI2SB-19:** This site is located within the footprint of former Thornock Lake process pond, which underwent remediation between 1986 and 1991. The soil boring (and associated surface soil sampling) was eliminated with agency consent because of the presence of overhead power lines and the availability of existing data from the area.

- Soil boring RFI2SB-3 was moved approximately 175 feet south of the location proposed in the work plan. The location was modified because of limited access to the proposed drilling area (soft soils). It was decided that relocating the boring to the south edge of Tito Park would provide valuable information on subsurface characteristics and potential contaminant sources near the southern-most (upgradient) extent of the current arsenic plume.
- Soil boring RFI2SB-11, located west of the Facility near the stormwater containment tank, was moved approximately 250 feet west of the original location and completed as a monitoring well (which was not proposed in the work plan). The boring was relocated and completed as a monitoring well (EH-210) to provide deeper hydrologic information to complement information from adjacent shallow monitoring well EH-205.

6.2.2.3.3 Monitoring Wells

- EH-140 was not installed and soil samples were not collected.

6.2.2.4 Summary of 2010 Surface Soils from BERA

As discussed previously, the BERA was conducted in 2010 to estimate the likelihood and magnitude of unacceptable risks to ecological receptors posed by potential exposures to metals in soil and other media. Soil sampling results are provided in Appendix 6-D. A total of 35 samples was collected from surface soils from a depth of 0 to 0.5 foot in the following locations (see Figure 6-3).

- Prickly Pear Creek riparian zone (4 samples)
- Upper Lake bank area (4 samples)
- Lower Lake bank area (4 samples)
- Walker Creek bank area (5 samples)
- Tito Park (5 samples)
- Site Perimeter, including lower ore storage and unpaved areas (13 samples)

Samples were analyzed for 19 metals. The mean, 95 percent upper confidence limit (UCL) on the mean, and maximum concentrations were used to determine ecological risk. Soil sample locations and results for the 2010 BERA are provided in Appendix 6-E. The BERA evaluated both the aquatic and terrestrial environments on and near the Facility and concluded that concentrations of several metals in surface soils are elevated to an extent that could pose a risk to ecological receptors. Specific conclusions for each habitat and receptor are provided in the BERA report (Gradient, 2010b) and are summarized below:

- The primary COCs for ecological receptors throughout most areas sampled are arsenic, cadmium, copper, mercury, lead, and selenium.

- Metals that could pose ecological risks in the areas sampled near the Facility's perimeter are antimony, manganese, silver, thallium, and zinc.
- Metals that are not elevated above reference areas are aluminum, barium, beryllium, chromium, cobalt, iron, nickel, and vanadium.
- The current concentrations of metals in Prickly Pear Creek and associated riparian areas appear to pose a minimal risk and are generally within the range of concentrations found outside of the influence of the Facility.
- Metal concentrations are elevated in portions of Upper Lake and Upper Lake Marsh, particularly at the north side, adjacent to Tito Park. Overall risk estimates for this area are low to moderate.
- Lower Lake and Tito Park have significantly elevated concentrations of metals in soils. In addition, Lower Lake appears to provide a source of metals to adjacent areas (i.e., groundwater and Prickly Pear Creek). This area of the Facility may need to be prioritized for further remedial investigations and cleanup activities to reduce the transport of metals to surrounding ecological habitats.
- The East and West Perimeter of the Facility is characterized by elevated metal concentrations and ecological risks from soil exposure are high. Additional remedial activities may need to be undertaken to reduce exposure.

6.2.2.5 Surface Soil Sample Analyses Results

During the 2010 surface soil sampling conducted for the Phase II RFI, 82 samples were collected from the zero to 0.5-foot depth interval, and 97 samples were collected from the 0.5- to 5.0-foot depth interval. Table 6-3 summarizes the metals results for zero to 0.5-foot interval samples and Table 6-4 summarizes metals results for soil samples collected from the 0.5- to 5.0-foot interval.

Aluminum, arsenic, cobalt, copper, iron, manganese, vanadium, and zinc were detected in all surface soils samples from the zero to 0.5-foot interval. Beryllium was not detected in these samples. Average concentrations of metals detected in these samples were generally lower than average concentration of metals detected below 0.5 foot. The highest concentrations of metals at this depth interval were consistently detected at RC-SS5 located along the former rail corridor. Relatively high concentrations of metals also were detected in the samples collected at RC-SS7 and RFI2SB-8, both located west of RC-SS5.

As with the samples from the uppermost depth interval, aluminum, arsenic, iron, lead, manganese, vanadium, and zinc were detected in all the samples from the 0.5- to 5.0-foot depth interval, and beryllium was not detected. On average, concentrations of arsenic, barium, cadmium, copper, and lead were highest in the 0.5- to 5.0-foot layer of soil. The highest concentrations of metals at this depth interval were consistently detected in soil boring RFI2SB-6, located in the southeast corner of the former Monier Flue, and at RFI2SB-18, located immediately east of the former Acid Plant settling pond.

6.2.3 Phase II RFI Subsurface Soil Sampling

6.2.3.1 Soil Boring/Monitoring Well Sites

In addition to the surface soil sampling described above, the Phase II RFI included subsurface soil sampling. For purposes of this Phase II RFI report, subsurface soil samples are defined as those collected from depths greater than 6 feet. Subsurface soil sampling was conducted at the same soil borings and monitoring well locations discussed above in Section 6.2.2.2 and shown in Figure 6-3. The subsurface sampling sites are described in Table 6-2.

The primary objectives of the subsurface soil sampling included the following:

- Providing information on the distribution of metals in the subsurface soils;
- Evaluating relationships between subsurface soil concentrations and the arsenic and selenium groundwater plumes; and
- Delineating the soil stratigraphy beneath the Facility, particularly the occurrence of the low-permeability weathered clayey ash unit (i.e., Aquitard).

Additional boring-specific objectives are discussed above in Section 6.2.2.2.

All soil boring and monitoring well locations were recorded for horizontal and vertical control using a resource-grade GPS unit. Select split-spoon and core samples were photographed, with project photos included in the project file. Phase II soil boring logs are included in Appendix 5-E. Geologic and hydrogeologic information obtained from the drilling program is presented in Section 5.

6.2.3.2 Deviations from the *Phase II RFI Work Plan* for Subsurface Soils

The subsurface soil sampling was conducted in accordance with the *Phase II RFI Work Plan* with a few deviations based on field conditions and/or opportunities to collect additional data or information. Deviations from the work are described in Section 6.2.2.3 and are summarized as follows:

- Soil boring RFI2SB-3 was moved approximately 175 feet south west of the original location.
- Soil boring RFI2SB-11 was moved approximately 250 feet west of the original location.
- Proposed soil boring RFI2SB-19 was not completed.
- Proposed monitoring well EH-140 was not installed because of concerns with drilling through a potential aquitard (see Appendix 5-D).

6.2.3.3 Subsurface Soil Sample Analyses Results

In 2010, 288 subsurface soil samples were collected from the 20 borings and 9 monitoring wells. Results for these samples are summarized in Table 6-5. As in the surface soils, aluminum, barium, iron, lead, manganese, and zinc were detected in all samples collected. Beryllium and mercury were detected in relatively few of the subsurface samples. On

average, subsurface concentrations of aluminum, iron, selenium, and zinc were slightly higher than concentrations of metals detected in surface samples.

The maximum arsenic concentration (11,600 mg/Kg) was detected at soil boring RFI2SB-18, near the former Acid Plant. This sample was collected from a depth of 5 to 7 feet and consisted of unsaturated slag and granular fill. Boring RFI2SB-18 is located on the east margin of the former Acid Plant settling pond, which was excavated to depths up to 20 feet and backfilled in 1993.

The highest concentrations of metals in the subsurface soil samples were consistently observed in soil boring for monitoring well DH-75 and DH-76, both located within the slag pile. The highest soil concentrations from samples not containing slag was recorded at boring RFI2SB-3 (2,850 mg/Kg), located on the southern portion of Tito Park near Upper Lake. This sample was collected from a depth of 5 to 7 feet (immediately above the water table) and included silty sand fill with wood and brick debris. Both of these samples were included in the leach testing program and produced relatively high leachate concentrations (see Section 6.7). Selenium concentrations in subsurface soils were relatively low, with a mean concentration of 43 mg/Kg. Of the 288 subsurface soil samples tested, 60 contained selenium at concentrations greater than the detection limit (5 mg/Kg). Soil borings with notable selenium concentrations include RFI2SB-3 (53 mg/Kg), SB-6 (106 mg/Kg), SB-9 (281 mg/Kg), and SB-18 (126 mg/Kg). Additional observations on arsenic and selenium concentrations in subsurface soils collected in 2010 include:

- Soil samples that contained slag (used as fill or from slag pile borings) had some of the highest arsenic concentrations. Selenium concentrations in slag were variable, with the highest concentrations found in the upper 40 to 50 feet of slag (DH-74).
- Concentrations of arsenic and selenium were generally greatest in the unsaturated zone, with the highest concentrations occurring immediately above the water table in a number of cases (i.e., RFI2SB-3).
- Soil Boring RFI2SB-15 near the former zinc plant contained the highest selenium concentration (668 mg/Kg) in a shallow sample (zero to 6-inch) containing brick and slag debris. Overall, however, arsenic and selenium concentrations were relatively low in the zinc plant area.
- Soil samples collected beneath the slag pile (soil borings advanced for construction of monitoring wells DH-74, -75, and -76) were all relatively low in arsenic and selenium, with selenium concentrations less than 5 mg/Kg in 20 of 21 samples.
- Arsenic and selenium concentrations were low in both unsaturated and saturated zone soil at all offsite borings.

In addition to the elevated arsenic and selenium, subsurface soil samples contained elevated antimony, cadmium, copper, lead, manganese, mercury, thallium, and zinc. In general, the extent of contamination of these additional metals was limited to soil borings within known source areas (Tito Park, former Acid Plant, and the slag pile). Findings of the soil sampling program are discussed further in terms of contaminant fate and transport in Section 11 of this Phase II RFI report.

The subsurface soil analyses included testing of eight samples for volatile petroleum hydrocarbons (VPH) and extractable petroleum hydrocarbons (EPH) based on evidence (staining, odor) of petroleum contamination. These samples were collected at the water table from boring RFI2SB-7 (upgradient of the Speiss/Dross Area), and borings RFI2SB-16, -17, -20, and -21 (downgradient of this area). Analytical results for VPH and EPH are presented in Table 6-5. VPH contaminant concentrations were generally low, with the majority below the analytical detection limits. The sample taken from 25 to 27 feet in soil boring RFI2SB-20 had the highest concentrations of VPH, although still relatively low. EPH contaminant concentrations, which includes the heavier hydrocarbon ranges, were generally higher than VPH. As with the VPH analyses, soil boring RFI2SB-20 had the highest EPH concentrations at the 25- to 27-foot sample interval. The higher concentrations in the EPH range suggest that the petroleum contamination originated from a release of diesel or heavier petroleum product. The current hydrocarbon fractionation is affected by weathering of the hydrocarbons.

6.3 Soil Screening

Existing site data for contaminants detected in surface and subsurface soils were compared with EPA Regional Screening Level Values (SLV) (EPA, 2010a) to identify a preliminary list of COPCs for protection of human health from direct contact, incidental ingestion of soil, and leaching of contaminants to groundwater at concentrations exceeding the maximum contaminant level (MCL). This section screens individual sample point results relative to these SLVs. It is important to recognize that this screening provides a conservative assessment of potential risks and is not necessarily indicative of actual or site-specific risks. Direct evaluations of site-specific ecological risk are addressed in the BERA (Gradient, 2010a). Direct evaluations of site-specific risk to human health will be addressed in the HHRA, which is currently under development.

EPA Regional Screening Level (RSL) values for contaminant concentrations detected in surface soil zero to 6 feet bgs are:

- Industrial SLVs;
- Residential Soil Screening Levels; and
- MCL Protection of Groundwater Soil Screening Levels (SSL)

For soil deeper than 6 feet, the screening levels considered are:

- MCL Protection of Groundwater SSLs

Results of preliminary screening of pre-2010 and 2010 sample results for inorganic contaminants sample results are presented in Appendix 6-F. In addition to SLVs, results were compared with regional background concentrations (see Table 4-2). Tables 6-6 through 6-8 summarize preliminary screening evaluation results for surface soil samples, and Table 6-9 summarizes preliminary screening evaluation results for subsurface soil samples.

6.4 Contaminants of Potential Concern

COPCs for surface soils at the Facility identified in Appendix 6-F are antimony, arsenic, barium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, selenium, silver, thallium, vanadium, and zinc. The list of COPCs for subsurface soils includes arsenic, barium, beryllium, cadmium, copper, lead mercury, selenium, and thallium.

6.5 Distribution of Soil Contamination

Figures 6-4 (a through f) through Figure 6-15 (a through f) illustrate the distribution of current metal concentrations in Facility soils. Soil concentrations are mapped for depth intervals of zero to 0.5 foot; 0.5 to 3 feet; and 3 to 6 feet; 6 to 10 feet; 10 to 20 feet; and >20 feet bgs for antimony (Figures 6-4a-f), arsenic (Figures 6-5a-f), cadmium (Figures 6-6a-f), chromium (Figures 6-7a-f), copper (Figures 6-8a-f), iron (Figures 6-9a-f), lead (Figures 6-10a-f), manganese (Figures 6-11a-f), mercury (Figures 6-12a-f), silver (Figures 6-13a-f), selenium (Figures 6-14a-f), zinc (Figures 6-15a-f), and total extractable hydrocarbons (Figure 6-16).

6.5.1 Surface Soil

This section presents a summary of the distribution of COPCs in surface soils (i.e., zero - 6 feet) at the Facility. Arsenic occurs at elevated concentrations in surface soils⁸ throughout the Facility. Figure 6-5 (a through c) illustrates the arsenic concentrations in surface soils from depth intervals of zero to 0.5 foot, 0.5 to 3 feet, and 3 to 6 feet. As described above, the arsenic concentrations in most of these samples exceed the applicable SLVs. The highest arsenic concentrations in surface soil at the Facility are observed at the following general areas:

- Zero to 0.5 foot depth interval: Arsenic concentrations >2,900 mg/Kg (i.e., 1,800x the industrial soil SLV) are located on the western half of the Facility and in the rail car staging area northwest of the Facility. Concentrations (>290 mg/Kg) are widespread across the facility.
- 0.5 to 6 feet. Arsenic concentrations are generally highest in the western area of the Facility and in the vicinity of the former Acid Plant water treatment settling facility area.

The highest lead concentrations in surface soil (Figure 6-10a) at the Facility are observed at the following general areas:

- Zero to 0.5 foot depth interval: Lead concentrations >14,000 mg/Kg (i.e., 20x the industrial soil SLV) are located on the western two-thirds of the Facility and in the rail car staging area northwest of the Facility. Concentrations (>1,400 mg/Kg) are widespread across the facility.
- 0.5 to 6 feet. Lead concentrations generally exceed 1,400 mg/Kg in the western half the Facility from 0.5 to 3 feet bgs. Concentrations decrease in the 3 to 6 feet depth

⁸ For the purpose of this evaluation, surface soils are considered to be from depths of 6 feet or less, for consistency with the screening evaluation.

interval and concentrations > 1,400 mg/Kg are located primarily along the western property boundary and in the vicinity of the former Acid Plant water treatment settling facility area.

The distribution of other metals, including antimony, cadmium, chromium, copper, iron, manganese, mercury, silver, and zinc are shown in Figures 6-6 through 6-16. Manganese, selenium, silver, and zinc do not exceed the industrial SLV in soil. The highest concentrations (>260 mg/Kg) were detected in the Monier Flue and blast furnace flue areas. However, concentrations are less than the industrial SLVs. Samples from these areas are elevated in most inorganic contaminants.

6.5.2 Subsurface Soil

This section presents a summary of the distribution of COPCs in subsurface soils (i.e., >6 feet bgs) at the Facility. Arsenic is elevated in subsurface soils throughout the Facility, as shown in Figure 6-5 (d through f). The highest arsenic concentrations in subsurface soils are observed in the center of the Facility in the former Acid Plant water treatment settling facility area, in the Speiss Handling Area, and at the western border of the Facility and generally appear to increase with depth.

Lead concentrations in subsurface soils, as shown in Figure 6-10 (d through f) are generally <1,400 mg/Kg, with the highest concentrations located along the western boundary of the Facility.

Selenium concentrations in subsurface soils (depicted in Figure 6-14, d through f) are elevated in the Tito Park area, underneath the slag pile, and in the former Acid Plant shop and Baghouse Flue areas. The detection limit for selenium was too high (5 mg/Kg) to determine if selenium exceeded protection of groundwater screening criteria (0.26 mg/Kg) or the background concentrations (0.07 mg/Kg).

The distribution of other metals, including antimony, cadmium, chromium, copper, iron, lead, manganese, mercury, silver, and zinc, in subsurface soils is shown in Figures 6-6 through 6-16.

Table 6-10 presents an evaluation of the distribution of metals in soil samples from the 2010 Phase II RFI soil borings.

6.6 Adsorption/Leach Testing

The objectives of the Phase II RFI soil adsorption/leach testing program (Hydrometrics, 2010a) were to:

- Characterize the relative availability of soil selenium (and arsenic) in potential source areas to groundwater;
- Assess the adsorption/desorption behavior of selenium and arsenic in different areas of the Facility, and the relationship of attenuation mechanisms to the configuration of the groundwater arsenic and selenium plumes; and
- Support development of the groundwater fate and transport model by refining the CSM for selenium and arsenic behavior in soil and groundwater at the Facility.

Soil samples for adsorption/leach testing were obtained from selected soil borings advanced during the Phase II RFI activities. Locations of the Phase II RFI soil borings (locations RFI2SB-1 through RFI2SB-18, and RFI2SB-20 through RFI2SB-22) and boring locations for onsite monitoring wells (DH-72 through DH-76) are shown in Figure 6-3. Samples were selected for adsorption/leach testing based on the observed total selenium and arsenic results, on the sample locations relative to the current arsenic and selenium groundwater plume configurations observed at the Facility, and on the objectives outlined above. Table 6-11 summarizes the Phase II RFI soil samples selected for extraction/adsorption testing of selenium and arsenic, along with sample information (location and depth), total arsenic and selenium concentrations, and rationale for inclusion of the particular sample in the testing program.

Soil adsorption and leach testing consisted of four tests:

- Synthetic Precipitation Leaching Procedure (SPLP; EPA Method 1312);
- Sequential Batch Leach Tests (modified EPA Method 1312);
- Sequential Extraction Tests (USGS, 2006); and
- Batch Adsorption Tests (modified EPA Method 1312 as described in EPA, 1992).

Description of the test methods are provided in Appendix 6-I. Results of the adsorption/leach testing are discussed below.

6.6.1 SPLP Test Results

Results of the SPLP tests are included in Appendices 6-G and 6-H and summarized in Table 6-12. The SPLP test results highlight the differences between arsenic and selenium solubility and the variations in soils from different areas of the Facility. Overall, selenium in soils and slag is much more leachable than arsenic, by a factor of approximately 10 to 30. The percentage of the total soil selenium leached in the SPLP tests ranged from 0.1 to 10.2 percent with a median of 1.3 percent. The percentage of the total soil arsenic leached in the SPLP tests ranged from 0.003 to 1.68 percent with a median of 0.043 percent.

The soils with the highest percentage of leachable selenium were found in the rail corridor and former Acid Plant area (median leachable percentages 4.7 and 3.4, respectively). However, rail corridor soils were quite variable, with half of the samples exhibiting less than 0.3 percent leachable selenium, suggesting that rail corridor soils are quite heterogeneous. Highest leachable concentrations of selenium occurred in rail corridor soils (up to 0.49 mg/L) and slag (up to 0.40 mg/L). Eleven of the 20 soils tested leached selenium at concentrations exceeding the MCL of 0.05 mg/L). SPLP testing suggests that, although selenium concentrations in site soils are not high, at least in comparison to arsenic, the selenium in soils is in a form that is capable of generating leached solution concentrations that may exceed groundwater standards.

Soils were found to be relatively uniform in terms of percentage of leachable arsenic, with Tito Park, Acid Plant, and slag soils exhibiting median leachable percentages of from 0.12 to 0.14 percent. The highest leachable concentrations of arsenic occurred in Tito Park soils (up to 2.4 mg/L) and Acid Plant (up to 2.0 mg/L). Fourteen of the 20 soils tested leached

arsenic at concentrations exceeding the MCL of 0.01 mg/L. SPLP testing suggests that although the surface soils do not leach arsenic in the concentrations observed in groundwater near historic sources (e.g., Speiss Pond), the arsenic in soils is in a form that is capable of generating leached solution concentrations that may exceed groundwater standards.

6.6.2 Sequential Batch Leach Test Results

Results of the sequential batch leach tests are included in Appendices 6-G and 6-H and summarized in Table 6-13. Sequential batch leach test results demonstrate the long-term leaching behavior of soils. Leached concentrations of both arsenic and selenium generally declined with repeated leaching, with a few exceptions. All soils leached arsenic at concentrations greater than the MCL (0.01 mg/L) throughout the tests, with the exception of soil from boring RFI2SB-6 (2.5- to 5-foot depth interval) collected from the unsaturated zone in the area of the Monier Flue. For selenium, two of the three soil samples (from Monier Flue and Acid Plant) initially leached concentrations in excess of the MCL (0.05 mg/L). With repeated leaching, concentrations leached from the Monier Flue sample decreased to below the MCL, whereas concentrations leached from the Acid Plant remained above the MCL throughout the testing.

6.6.3 Sequential Extraction Test Results

Results of the sequential extraction tests are included in Appendices 6-G and 6-H and summarized in Table 6-14. Sequential extraction results demonstrate that the primary arsenic and selenium-bearing phases in soils varies with location and differs between soils and slag. For the two slag samples, 92 to 95 percent of the selenium occurs as sulfides/selenides and as residual phases, possibly as silicate minerals and glass. Similarly, the highest percentage of arsenic in the slag (28 and 29 percent) was found in the sulfide/selenide fraction. The occurrence of arsenic and selenium in sulfides/selenides in the slag may result from residual ore minerals that were not fully melted and/or reacted in the smelting process. In the soil samples, the primary arsenic and selenium phases varied from soil to soil, possibly reflecting the variability of the source and nature of the soil contamination at the Facility.

6.6.4 Batch Adsorption Test Results

Results of the batch adsorption tests are included in Appendices 6-G and 6-H and summarized in Tables 6-15 through 6-17. None of the 17 soil samples tested demonstrated any capacity for selenium adsorption with any of the three groundwater solutions, which varied in concentration from 0.118 to 0.532 mg/L. In virtually all of the tests, selenium was leached from the soils by the groundwater solutions.

Arsenic was adsorbed by most of the soils tested, with the amount of adsorption dependent on the solution concentration. The relationship between the amount of arsenic adsorbed by the soil and solution concentration (i.e., adsorption curves or isotherms) was evaluated by three commonly used equations: Freundlich Equation, Langmuir Equation, and a linear equation. Parameters for each of these equations are shown in Table 6-18. The “goodness of fit” or r^2 value for some of the equations was relatively poor, particularly in tests where the amount of arsenic adsorbed was very high (e.g., sample from RF12-SB6 [2.5- to 5-foot depth interval, with 75 to 98 percent of solution arsenic adsorbed]). Additionally, in many cases

the r^2 value can be improved by omitting the test results for the 1:60 and/or 1:100 soil:solution ratio tests where the amount adsorbed was lower than approximately 20 percent. The reason that the 1:60 and/or 1:100 soil:solution ratio tests do not fit well may be related to three factors:

1. The difficulty of achieving a representative soil sample when testing small amounts of soil. In the 1:60 and 1:100 ratio tests, the amount of soil tested was relatively small, approximately 2 to 3 grams;
2. Competition from other ions for adsorption sites; and/or
3. Saturation of adsorption sites on the soil to the point that further adsorption is limited even with increased solution concentration.

6.7 Contaminant Fate and Transport

6.7.1 Contaminant Transport Mechanisms

Contaminants present in soil at the facility may be transported via stormwater erosion, wind erosion, or vehicle tracking, or be leached by infiltrating stormwater or snowmelt to groundwater. Contaminants in the saturated zone or within the zone of seasonal groundwater level changes also may be leached and be transported with groundwater.

6.7.2 Contaminant Fate

Metal contaminated surface and subsurface soils at the Facility may be leached by the stormwater, snowmelt, or groundwater moving (e.g., infiltrating) through the soil. Typically, the more precipitation, the greater the chance for contaminant to leach. Leaching is a concern because of the potential for a contaminant to move through the soil, contaminate groundwater, and to migrate to the capture zone of a private or public drinking water well. Many factors (e.g., chemical, physical) affect whether a contaminant will leach from soil and then migrate to a potential receptor (e.g., surface water body, drinking water well). Soil leaching and groundwater contaminant fate and transport are discussed in Section 11.

6.8 Areas of Potential Concern

Leaching of surface and subsurface concentrations of antimony, arsenic, cadmium, copper, lead, manganese, mercury, and selenium all pose a threat to groundwater quality in widespread areas across the site. The following were identified as AOPC based on the high metals concentrations, which may pose potentially unacceptable risks to groundwater and/or human health based on the conservative screening conducted in this section:

- Near the northwest corner of the Concentrate Storage and Handling Building (CSHB)
- Along the alignment of the buried pipe conveying water from Upper Lake to Wilson Ditch along the western Facility boundary;
- The Lower Ore Storage Yard;

- Tito Park; and
- The Former Acid Plant Drying Pads area.

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7 Groundwater

7.1 Summary of Previous Investigations

Historically, groundwater has been the focus of several investigations at the Facility. Comprehensive descriptions of previous work are presented in Section 2.3.4. Early groundwater investigations were conducted as part of the *Comprehensive RI/FS* during the mid-1980s (Hydrometrics, 1990). This work included an initial characterization of the nature and extent of groundwater contamination as well as defining the hydrogeologic framework beneath the facility and surrounding area. The RI/FS and subsequent investigations led to implementation of interim remedial measures in the 1990s to control sources and reduce metals loading to groundwater. These interim remedial measures focused on the former Speiss-Dross, Acid Plant, and Acid Plant sediment drying areas and included onsite soil removal, sediment dredging, temporary capping of remediated areas where residual contamination in subsurface soil was suspected.

The CC/RA report (Hydrometrics, 1999a) provided an update of groundwater conditions following the interim remedial measures and determined that groundwater quality on the Facility had improved substantially because of the interim remedial measures.

Post-RI/FS (long-term) groundwater and surface water monitoring has been conducted at the Facility from 1991 to the present. This monitoring program consists of semiannual (usually in May/June and October/November) water level monitoring and groundwater sampling at up to 160 monitoring wells (including 15 wells installed in 2009), several residential wells, municipal and industrial water supply wells, and surface water sampling locations on Prickly Pear Creek and Lower Lake. In addition to the Post-RI/FS Semiannual Monitoring Program, quarterly monitoring of the CAMU wells is required under the *Consent Decree*. The water quality data and most water level measurements generated through the long-term monitoring program are included in the project database. An inventory of wells and water usage, and a compilation of existing water data were prepared by Hydrometrics and are provided as Appendices 7-A and 7-B, respectively. A compilation of key groundwater figures and tables from previous investigations is provided in Appendix 7C.

Relevant findings of the ongoing groundwater monitoring programs are as follows:

- The primary aquifer underlying and downgradient of the Facility is composed of unconsolidated alluvial/colluvial sediments. Beneath the majority of the Facility, this shallow unconfined to semi-confined aquifer consists of a 15- to 20-foot-thick saturated sand and gravel unit with the aquifer base defined by a low permeability weathered tuffaceous sediment layer. In the northern portion of the Facility, the aquifer thickens to approximately 30 feet with an increasing presence of discontinuous fine-grained (silt) lenses within the sand and gravel matrix. In previous investigations (ACI, 2005), the upper aquifer was divided into a shallow

aquifer and deeper “intermediate” aquifer based on the presence of these fine-grained lenses. Based on further review of available information, including drilling of 15 additional wells in 2009, the shallow and deeper portions of the upper aquifer are believed to be in direct hydrologic communication and to act as a single shallow aquifer system. Hydrostratigraphy of the Facility area is discussed further in Section 5.

- Groundwater at the site flows in a north to northwest direction from the Facility and fluctuates seasonally based on variations in recharge sources.
- Seepage from Upper Lake and Lower Lake provide a continuous recharge source to groundwater. Other significant sources of recharge include year-round seepage from Prickly Pear Creek north of the Facility and seasonal seepage during the irrigation season from Wilson Ditch west of the Facility. Other sources of recharge include precipitation and snow melt, upward groundwater flow from underlying units and inflow from the surrounding foothills.
- Monitoring results have detected elevated arsenic concentrations in the Upper Aquifer, with the mapped plume trending from the Facility property to the north and northwest of the Facility property. Previously identified arsenic source areas include: Lower Lake, the former Speiss-Dross Area, the former Acid Plant, and former APSD areas. These source areas have been the focus of interim remedial measures, including the recent (2006/2007) encapsulation of contaminated soils in the Speiss-Dross and APSD areas within slurry walls and placement of temporary caps.
- In the past few years, elevated concentrations of selenium also have been detected in the Upper Aquifer extending from the Facility to the north and northwest. Selenium data for the Facility are limited. A summary of historic selenium concentrations in select wells is provided in Table 7-1.
- The northward extent of the arsenic plume is reasonably well defined by previous investigations. While site investigations in 2009 led to better delineation of the selenium plume, the downgradient (northwest) extent of the plume was not fully defined.

Full delineation of the selenium (and arsenic) groundwater plumes, as well as characterization of the plume characteristics and source areas, is a primary objective of the Phase II RFI.

7.2 Phase II RFI Investigation

The Phase II RFI represents a continuation of previous site characterization and evaluation programs, most notably the *Comprehensive RI/FS*, *CC/RA*, and the *Phase I RFI*, and relies heavily on data and information obtained through those programs.

The Phase II RFI groundwater monitoring program consisted of both water level and water quality monitoring. The water level monitoring information is discussed primarily in Section 5.3. This section of the report focuses on water quality monitoring.

For completeness, results from all 2010 groundwater sampling events are included for discussion in this report. This includes the Post RI/FS Semiannual Monitoring Program, CAMU Monitoring Program, Selenium Plume Front Monitoring Program, supplemental sampling of 2009 Monitoring Wells, and Initial Sampling of Phase II RFI Monitoring Wells. The monitoring program objectives and methodology are discussed in Appendix 4-A.

7.2.1 Phase II RFI Monitoring Well Installation and Testing

Nine monitoring wells were installed in August and October 2010 as part of the Phase II RFI Site Characterization within the Facility and north/northwest of the Facility as shown in Figure 7-1 and Exhibit 1. The Phase II RFI monitoring wells were installed to further evaluate:

- Groundwater concentrations in contaminant source areas
- Horizontal and vertical extent of arsenic and selenium contamination in groundwater (i.e., contaminant plumes)
- Vertical hydraulic gradients within the Upper Aquifer and between the Upper Aquifer and the underlying tuffaceous/volcaniclastic deposits
- The nature (e.g., presence, depth, etc.) of the weathered clayey ash Aquitard (base of Upper Aquifer) both beneath and in the vicinity of the Facility

Several well pairs (i.e., adjacent wells with their screened intervals vertically separated) were installed to further understand the vertical extent of groundwater contaminants and vertical hydraulic gradients. Specific objectives of each Phase II RFI monitoring well are discussed below.

Borings were drilled using Air-Rotary (Tubex) and Sonic drilling techniques to penetrate the boulders, cobbles, and gravel typical of the City of East Helena area. Completed monitoring wells are constructed of 2-inch-inside-diameter (ID) schedule 40 PVC with flush threaded joint couplings and a 10-foot-long, 0.010-inch factory slotted screen section. The borehole annulus is backfilled with silica sand from the well bottom to 3 feet above the top of the screen to provide a filter pack. The remainder of the borehole annulus was backfilled with bentonite chips/pellets to seal the borehole annulus and prevent fluid migration along the outer well casing. Well construction and grouting details are consistent with State of Montana monitoring well construction regulations (ARM 36.21.800). Following well construction, the new monitoring wells were developed to remove fine sediments from the screen interval and improve the hydraulic connection with the aquifer. Well development procedures (see Appendix 4-A) were consistent with the *Phase II RFI Work Plan*. Aquifer tests were conducted using pneumatic slug testing procedures to estimate aquifer hydraulic conductivity and transmissivity at the each of the new monitoring wells. Aquifer test results are presented in Section 5.3.

Drilling and monitoring well construction were supervised by a qualified scientist or engineer, with detailed lithologic and construction logs recorded on field forms and a project field book. Monitoring well locations and measuring points (typically top of the PVC casing) were surveyed following well completion. Well completion and survey details are summarized in Table 7-2 and well locations are shown in Figure 7-1. Monitoring well logs are included in Appendix 5-E. Additional information regarding monitoring well

installation procedures, sampling procedure, and deviations from the *Phase II RFI Work Plan* (Hydrometrics, 2010a) are discussed in Appendix 4-A.

Phase II RFI monitoring wells were completed at three different target depths to characterize vertical extent of contamination and measure vertical hydraulic gradients within and between aquifer units. The shallow and intermediate wells were completed at different depths in the uppermost alluvial/colluvial aquifer. The deep monitoring wells were completed below the upper aquifer in the early Tertiary sediments, which is considered to be a separate hydrogeologic unit.

Three monitoring wells (DH-74, DH-76, and EH-70) were completed in the upper portion of the saturated alluvial aquifer (i.e., near the water table) and are identified as “shallow” monitoring wells. Two of the shallow monitoring wells (DH-74 and DH-76) were completed beneath the slag pile to characterize groundwater quality impacts immediately beneath the slag. Four monitoring wells (DH-73, DH-75, EH-138, and EH-139) were completed in the lower portion of the upper alluvial aquifer and have been identified as “intermediate” monitoring wells.

Downgradient of the Facility, shallow monitoring well EH-70 was completed in the upper portion of the alluvial aquifer and paired with intermediate well EH-125 to evaluate vertical gradients within the upper aquifer downgradient of the Facility.

Intermediate well DH-75, is paired with shallow well DH-74, to evaluate the vertical extent of contamination beneath the slag pile and, vertical gradients in the alluvial system. Intermediate well DH-73 is paired with shallow well DH-9, located at the southwestern base of the slag pile to further define the extent of the arsenic and selenium groundwater plumes near the slag pile and provide additional onsite vertical gradient data. The other two “intermediate” monitoring wells (EH-138 and EH-139) were drilled north of Lamping Field to define the northwest extent of the selenium plume.

7.2.2 Groundwater Quality Sampling

The 2010 groundwater monitoring well network is shown in Figure 7-1 and Exhibit 1. The network includes approximately 76 domestic wells, 125 project monitoring wells, 7 public utility wells, and 5 unclassified wells or piezometers. Groundwater quality monitoring was conducted in multiple events to fulfill various monitoring program objectives outlined in Section 4.

In 2010, post RI/FS groundwater samples were collected semiannually in June and October 2010. These events coincided with the June and October quarterly CAMU groundwater monitoring events. The third quarter CAMU monitoring event took place in August 2010. The first quarter CAMU monitoring event was not conducted because transfer of ownership of the Facility was commencing at this time, and contracts and sampling plans were not finalized. Additional deviations from the *Phase II RFI Work Plan* are described in Appendix 4-A.

In addition to the Post-RI/FS semiannual and CAMU monitoring events, additional monitoring was conducted to define and monitor the leading edge of the selenium plume and collect additional information from the monitoring wells that were installed in 2009. The objectives of these monitoring programs also are discussed in Section 4. The selenium

plume front monitoring involved collecting samples from four wells (EH-126, EH-129, EH-130, and EH-134) in the northern portion of Lamping Field in April, June, and July 2010. As outlined in the Hydrometrics, November 29, 2010, memorandum (Appendix 7-D(2)), two monitoring wells (EH-138 and EH-139) were installed and sampled north of the Facility (north of Lamping Field) in October 2010. Selenium concentrations detected in these wells resulted in the sampling and analysis of City of East Helena public water supply wells, nearby domestic wells, and several gravel ponds between these wells and Canyon Ferry Road in November 2010 to assess the northern extent of groundwater contamination. In March 2010, 15 monitoring wells that were installed in 2009, primarily in Lamping Field, were sampled and analyzed to provide water quality data to further define the extent of groundwater contaminant plumes and additional data for wells where limited samples had been collected and analyzed.

Groundwater samples were collected, handled, and analyzed in accordance with the *Phase II RFI Work Plan*, as described in Appendix 4-A, and submitted to Energy Laboratories in Helena, Montana, for analyses of physical parameters (e.g., pH, specific conductivity, temperature), common ions (e.g., major anions [chloride, sulfate, etc.] and cations [calcium, sodium, potassium, etc.]), and trace constituents (i.e., metals) using the methodology and detection limits listed in Table 7-3. Field parameters were tabulated by Hydrometrics and are provided as Table 7-4. Field sampling documentation is provided in Appendix 7-D(1).

7.2.3 Phase II RFI Monitoring Well Results

The combined results for the 2010 groundwater monitoring programs were tabulated and are included in Appendix 7-E and in the project database. This data compilation includes analytical results for dissolved, total, and total recoverable metals. Phase II RFI Laboratory Data Sheets are provided in Appendix 7-F. Analytical results for groundwater were screened and evaluated for the combined 2010 dataset as described in Sections 7.3, 7.4, and 7.6.

Water quality results from the recently installed Phase II monitoring wells are presented in Table 7-5. General observations from the groundwater sampling results from the Phase II RFI monitoring wells are listed below:

- Dissolved arsenic concentrations were elevated in shallow wells completed beneath the slag pile (DH-74 and DH-76) and were below or near the detection limit at the remaining Phase II RFI monitoring wells.
- Well pair DH-74/75 had elevated selenium concentrations, with the concentration in upper alluvial well, DH-74 (0.172 mg/L), detected approximately 5 times higher than the concentration in the lower alluvial well, DH-75 (0.035 mg/L).
- Dissolved selenium was detected above the MCL at downgradient EH-70 and EH-138.
- Sulfate concentrations were elevated in DH-73 and in wells where selenium concentrations were elevated.

These results are integrated with results of the comprehensive semiannual Facility monitoring programs in the following sections.

7.3 Groundwater Screening and Contaminants of Potential Concern

The 2010 Phase II RFI groundwater sample analytical results were screened against the project SLVs presented in Table 4-2. The 2010 dissolved metals concentrations in groundwater are compiled in Table 7-6 and are shaded. A similar table containing historic groundwater data is provided as Appendix 7-G. Basic statistics and a summary of SLV exceedances in 2010 by analyte are provided in Table 7-7. As shown in Table 7-7, project SLVs were exceeded for aluminum, antimony, arsenic, cadmium, lead, manganese, mercury, selenium, thallium, vanadium, and zinc. Given the SLV exceedances, these analytes represent COPCs for drinking water receptors. This analysis is generally consistent with an evaluation that screened groundwater data, collected between 2008 and 2010, against MDEQ groundwater standards (see Appendix 7-D(3)), with the exception that a lower screening level was used for iron (0.3 mg/L). Therefore, iron was identified as an additional COPC.

The frequency of detection for dissolved metals in 2010 ranged from zero percent (for silver, gold, and tellurium) to 73 percent (for selenium). Selenium and arsenic had the highest frequencies of detection in groundwater (73 percent and 69 percent, respectively). Of the detected results, 25 percent of the selenium concentrations exceeded the SLV and 50 percent of the arsenic concentrations exceeded the SLV. Copper and iron were detected in groundwater samples, at a frequency of 50 percent and 25 percent, respectively, but all of the detected concentrations were below the SLVs. Manganese was detected in 29 percent of the groundwater samples, and of the detected results, 70 percent exceeded the SLV. Zinc was detected in 20 percent of the groundwater samples, but only 3 percent of those samples had concentrations exceeding the SLV. Although aluminum, antimony, lead, mercury, thallium, and vanadium were detected in less than 20 percent of the samples, the frequency of SLV exceedances in these detected results was greater than 50 percent. Barium, beryllium, cadmium, chromium, cobalt, nickel, and silver were detected in 12 percent or less of the groundwater samples, and no concentrations of these analytes exceeded the SLVs.

7.4 Distribution of Dissolved Metals in Groundwater

Figures 7-2 through 7-13 show the dissolved metals concentrations for the 2010 Phase II RFI groundwater samples for the 12 metals with the highest frequency of detection (Table 7-7). These analytes include antimony, arsenic⁹, cadmium, chromium, cobalt, copper, iron, manganese, selenium¹, thallium, vanadium, and zinc. For each analyte, two maps were prepared (one for the June to July 2010 data and the second for the October to December

⁹ The figures for arsenic and selenium display groundwater concentration surfaces generated from natural neighbor interpolations through a geographic information system (GIS). Natural neighbor interpolation defines areas of similar concentration using an algorithm that finds nearby samples surrounding a given point (i.e., well) and applies weights to them based on proportionate areas. The method does not infer trends and will not produce peaks, pits, ridges, or valleys that are not represented by the input data. These figures are utilized to approximate the potential extent of groundwater contamination of varying concentration. Using this method results in groundwater plumes that appear to consist of overlapping circular areas – these areas are not defined on the basis of site-specific hydrogeologic conditions and therefore should be used for information purposes only. Concentrations reported by the analytical laboratory as not detected were incorporated by assuming a value set at one-half the reported method detection limit.

2010 data), so that results for the different monitoring periods could be compared. The concentration ranges shown in Figures 7-2 through 7-13 generally reflect multipliers (0.5x, 1.0x, 2x, 10x, 100x, 1000x, and 10,000x) of the project SLVs for groundwater¹⁰. The distribution of mapped COPC metals is discussed below. Although aluminum, lead, and mercury also contained SLV exceedances and thus were identified as COPCs, the frequency of detection of these analytes was only 3 percent, 2 percent, and 1 percent, respectively. Based on the low number of detections for these three COPCs, maps showing their distribution were not generated.

7.4.1 Antimony

Figures 7-2a and 7-2b show the distribution of dissolved antimony in groundwater. The project SLV for antimony in groundwater is 0.006 mg/L. Dissolved antimony concentrations range from 0.003 mg/L to 0.0354 mg/L (APSD-8). Elevated antimony concentrations were observed near Lower Lake, Tito Park, the former APSD and Speiss-Dross areas, in a shallow well near where Wilson Ditch emerges from the piped portion, and in various locations within and underneath the slag pile. The antimony plume extends beyond the northern edge of the slag pile under Highway 12 and Prickly Pear Creek. The paired wells clusters EH-52/ EH-102 and EH-51/ EH-101 both had antimony detected in groundwater collected from the shallow alluvial well, but not the deeper alluvial well, indicating that the antimony plume may be confined to the Upper Aquifer.

7.4.2 Arsenic

Figures 7-3a and 7-3b show the distribution of dissolved arsenic in groundwater. The project SLV for arsenic in groundwater is 0.01 mg/L. Dissolved arsenic concentrations within the former active operations area of the Facility are typically at least 10 times the SLV. Arsenic concentrations are highest (more than 100 mg/L) within the previously identified source areas (i.e., Lower Lake, the former Speiss-Dross, Acid Plant, and APSD areas). Dissolved arsenic concentrations more than 1,000 times the SLV occur within and immediately downgradient of the former APSD and Speiss-Dross areas. The arsenic plume (shown as a natural neighbor contour map interpolation) encompasses much of the Facility property and extends about 2,000 feet northwest of Highway 12 into Lamping Field. A lower-concentration lobe of the arsenic plume also extends northerly from the eastern portion of the Facility and underlies a portion of the City of East Helena. The leading edge of the plume is well defined and appears to be fairly stable, as discussed further in Section 11. The current extent of the 0.010 mg/L (SLV) plume is limited to the area south of Clinton Street on the northern edge of the City of East Helena. Arsenic concentrations between the SLV and 100 times the SLV also are observed west of the Facility and along a short portion of Wilson Ditch (EH-132, EH-128, EH-206, EH-202, EH-203, and EH-201).

7.4.3 Selenium

Figures 7-10a and 7-10b show the distribution of dissolved selenium in groundwater. The project SLV for selenium in groundwater is 0.05 mg/L. The groundwater selenium plume consists of two "lobes," one centered on wells DH-8 and DH-66 in the western part of the Facility (western lobe), and the other on wells DH-56 and DH-6 in the eastern part of the

¹⁰ In the event, an SLV was not available, concentrations ranges were selected on the basis of the distribution of detected concentrations.

Facility (eastern lobe). Maximum selenium concentrations in the western lobe have reached more than 7 mg/L at well DH-66, and in the eastern lobe, maximum concentrations generally range from 1.0 to 1.5 mg/L. These two apparently distinct lobes of the selenium plume flank the former Speiss-Dross Area and merge into a single narrow plume beneath the City of East Helena. In comparison to arsenic, selenium concentrations extend much farther to the north through Lamping Field and beyond Canyon Ferry Road. Additional monitoring was conducted in October and November 2010 to define the leading edge of the selenium plume. Results from the selenium plume front monitoring efforts are included in the data depicted in Figure 7-10b and in Appendix 7-D. The fate and transport of selenium in groundwater (i.e., plume stability) is described in Section 11.

7.4.4 Cadmium

Figures 7-4a and 7-4b show the distribution of dissolved cadmium in groundwater. The project SLV for cadmium in groundwater is 0.005 mg/L. The maximum cadmium concentrations (up to 2.52 at well DH- 42) are contained within the center of the Facility near the former Speiss-Dross Area. With the exception of two wells, EH-100 and EH-109, located on the north side of Highway 12 (northwest of the Facility), all detections of cadmium are contained within the Facility property. Although detection of 0.002 and 0.003 mg/L were observed in EH-100 (in June 2010 and October 2010, respectively), no detection was observed in the shallower co-located well EH-50. Cadmium was detected at the detection limit of 0.001 mg/L in the nearby downgradient well EH-109 in June and October 2010. Cadmium concentrations detected in groundwater from both offsite wells are below the SLVs.

7.4.5 Manganese

Figures 7-9a and 7-9b show the distribution of dissolved manganese in groundwater. The project SLV for manganese in groundwater is 0.05 mg/L. Manganese detections ranged from 0.02 to 8.53 mg/L (EH-100). Concentrations more than 100 times the SLV are observed in the vicinity of Lower Lake and extend downgradient through the former Speiss-Dross Area and northwesterly across Highway 12. The highest concentrations were centered on the north side of Highway 12 between First Street and Second Street. This location corresponds to a trough in the underlying weathered tuffaceous sediment confining layer, which is discussed further in Section 11. The leading edge of the manganese plume appears to be well defined.

7.4.6 Thallium

Figures 7-11a and 7-11b show the distribution of dissolved thallium in groundwater. The project SLV for thallium in groundwater is 0.002 mg/L. Detections ranged from 0.002 mg/L to 0.131 mg/L (DH-59). All detections of thallium are contained on the Facility property and primarily are centered in the former Speiss-Dross Area with additional detections in several wells located within/under the slag pile. The detection limit for thallium is typically 0.001 mg/L, but it was elevated to 0.005 mg/L in six 2010 groundwater samples.

7.4.7 Vanadium

Figures 7-12a and 7-12b show the distribution of dissolved vanadium in groundwater. The project SLV for vanadium in groundwater is 0.0026 mg/L. Given that the detection limit for vanadium in many of the groundwater samples was 0.1 mg/L, the non-detected results do not confirm the absence of vanadium above the SLV; all samples analyzed at a lower detection limit had reported concentrations above the SLV. To determine the extent of vanadium contamination, additional groundwater samples would need to be collected and analyzed utilizing detection limits that are below the required SLVs.

7.4.8 Zinc

Figures 7-13a and 7-13b show the distribution of dissolved zinc in groundwater. The project SLV for zinc in groundwater is 5.0 mg/L. Only two detections of zinc were encountered above the SLV, both of which occurred in monitoring well SDMW-5, within the Speiss-Dross Slurry Wall. Offsite detections occurred in Lamping Field north of Highway 12, and are contained within the footprint of the arsenic plume.

7.4.9 Other Mapped Analytes

Figures 7-5(a,b), 7-6(a,b), 7-7(a,b), and 7-8(a,b) show the distribution of dissolved cobalt, chromium, iron, and manganese, respectively. Although no SLV exceedances were observed for these analytes, they were selected for mapping based on their relatively high frequency of detection to evaluate the spatial distribution of these analytes in relationship to the identified COPCs. In addition to the mapped analytes, groundwater within and, in some areas, downgradient of the Facility continue to exceed SMCLs for sulfate (250 mg/L), chloride (250 mg/L), and TDS (500 mg/L). However, given that SMCLs are guidelines established by EPA and are not considered to present a risk to human health at the SMCL, these parameters are not considered COPCs from a risk-based perspective, but rather are considered indicators of both historic Facility impacts to groundwater and of possible ongoing sources of contaminants to groundwater and are discussed more fully in Section 11.

7.5 Contaminant Fate and Transport

Contaminants dissolved in groundwater migrate advectively along groundwater flow paths. Groundwater level elevation maps shown in Section 5 (Figures 5-8 and 5-9) show a northerly regional groundwater flow direction in the Upper Aquifer. The groundwater flow direction is affected locally by recharge from Lower and Upper Lakes, Prickly Pear Creek, and Wilson Ditch.

At the upgradient margin of the Facility, groundwater is recharged from Lower Lake and Upper Lake. Flow in this area of the Facility is northward in a radial pattern caused by mounding from this recharge. A portion of the groundwater flow from Upper Lake is northerly toward Lower Lake and the slag pile on the east side of the Facility. There are also groundwater flow paths in a north/northwesterly direction that pass beneath the former Acid Plant and Speiss-Dross Plant on the west side of the Facility. Downgradient of the Facility, the groundwater flow is primarily northwesterly.

Groundwater flow rates are dependent on the aquifer properties and vary across the site. In general the upper alluvial/colluvial aquifer is more permeable than the finer-grained

Deeper Groundwater System. The highest hydraulic conductivities have been documented in the Upper Aquifer in the west Facility area, which includes the former Acid Plant and Speiss-Dross source areas, and out into Lamping Field.

Arsenic and selenium are the primary COCs in groundwater at the Facility. Both arsenic and selenium can occur in multiple oxidation states and chemical species, and their fate and transport in groundwater systems are thus closely linked to chemical (e.g., solubility, contaminant source concentrations, oxidation/reduction) and physical (e.g., advection, dispersion, dilution, aquifer permeability) conditions within the aquifer. Metals can be leached into groundwater from contaminated soils or removed from groundwater through adsorption to soils. Contaminants also may be exchanged between groundwater and surface water when a connection exists. Detailed discussions of contaminant migration pathways and the geochemistry of arsenic and selenium are presented in Section 11. In addition, several COPCs, including arsenic, selenium, manganese, and antimony, are observed within and underneath the slag pile. Of these, antimony and arsenic extend offsite in a northerly direction beyond Highway 12 and Prickly Pear Creek.

Although this report emphasizes current Facility conditions and presents figures depicting the current distribution of contaminants in groundwater, time-series plots of arsenic, chloride, selenium, and sulfate concentrations have been prepared for project monitoring wells and are provided Appendix 7-D5 for reference. Select time-series plots and plume maps from previous investigations are provided in Appendix 7-C. These figures are referenced because they provide additional insights into the fate and transport of chemicals in groundwater. The time-series plots indicate that COPC concentrations in groundwater vary seasonally.

Figures 7-14a and 7-14b show the relationship between groundwater flow patterns, the current extent of the dissolved arsenic and selenium plumes, and the top of the weathered tuffaceous sediment layer. The arsenic and selenium groundwater plumes correlate closely with the prominent northwest groundwater flow direction in this area. Additionally, there are also apparent correlations between the arsenic and selenium plumes and the erosional trough (or paleo-channel) in the top of the weathered tuffaceous sediment and groundwater mounding associated with surface water infiltration along Prickly Pear Creek. Seasonal infiltration from Wilson Ditch seems to influence both groundwater flow and contaminant distribution in the immediate vicinity of this ditch. Potential groundwater/surface water pathways are discussed further in Sections 8 and 11.

7.6 Areas of Potential Concern

As discussed in Section 7.3, the following dissolved metals were detected above project SLVs and therefore are identified as COPCs for groundwater: aluminum, antimony, arsenic, cadmium, lead, manganese, mercury, selenium, thallium, vanadium, and zinc. Arsenic and selenium have the greatest number of SLV exceedances and the largest plume footprints. Consequently, they are considered the primary Facility-related COPCs for groundwater. Most of the other COPCs are contained within the plume footprint of arsenic and/or selenium, but the spatial distribution of the individual COPCs varies, as discussed in Section 7.4.

The primary groundwater AOPC underlies the central portion of the Facility extending from Tito Park and Lower Lake downgradient beneath the former APSD and Speiss-Dross areas. This AOPC, defined by selenium concentrations above the SLV, extends in a northwesterly direction under Highway 12 approximately 1 mile.

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8 Surface Water

8.1 Summary of Previous Investigations

Surface water was evaluated as part of several previous investigations at the Facility, including the initial sampling conducted in 1984 and 1985 as part of the *Comprehensive RI/FS* (Hydrometrics, 1990), the *Post Remedial Investigation Well and Surface Water Monitoring Report* (Hydrometrics, 1995), *CC/RA* (Hydrometrics, 1999a), the *Phase I RFI* (ACI, 2005), and the *Supplemental Ecological Risk Assessment* (EPA, 2005). General findings from these previous surface water data collection efforts at the Facility are summarized below. Summaries of surface water quality data from these previous investigations were included in the BERA report (Gradient, 2010b) and are provided for reference in Appendix 8-A.

As part of the *Comprehensive RI/FS*, surface water was sampled from Prickly Pear Creek, Upper Lake, and irrigation ditches. The *Comprehensive RI/FS* (Hydrometrics, 1990) and *CC/RA* (Hydrometrics, 1999a) concluded that a measurable increase in arsenic concentrations in Prickly Pear Creek was observed during periods of low flow and that the increase was attributed to seepage from Lower Lake. In addition, the reports concluded that although the Prickly Pear Creek channel flows along the eastern and northern edges of the slag pile, long-term monitoring has not indicated that slag has measurable impacts on water quality over this reach.

During the Phase I RFI, surface water monitoring was conducted in 2001 and 2002 in Prickly Pear Creek, Upper Lake, Lower Lake, and Wilson Ditch to evaluate the effectiveness of corrective measures implemented on Lower Lake and any associated effects on Prickly Pear Creek water quality. The *Phase I RFI* (ACI, 2005) concluded that remedial actions implemented during the 1990s, including plant water treatment improvements and Lower Lake sediment removal, had resulted in significantly lower arsenic concentrations in Lower Lake and Prickly Pear Creek.

The 2005 *Supplemental Ecological Risk Assessment* included surface water sampling in Lower Lake, Upper Lake, Upper Lake Marsh, and Prickly Pear Creek (and Canyon Ferry Reservoir as a reference location). The report (EPA, 2005) concluded that for aquatic receptors, the risk of population-level effects to fish and benthic invertebrates from Facility-related contaminants detected in surface water was:

- Moderately high for fish and high for benthic invertebrates in Lower Lake
- Minimal to low for fish and low for benthic invertebrates in Upper Lake and the Marsh area
- Minimal for fish and minimal to low for benthic invertebrates in Prickly Pear Creek

Seasonal high flow and low flow monitoring data continue to be collected in Prickly Pear Creek, Upper Lake, and Lower Lake, as part of the CERCLA Post-RI/FS monitoring efforts.

8.2 Phase II RFI Surface Water Investigation

As described in the *Phase II RFI Work Plan* (Hydrometrics, 2010a) and *Post-RI/FS Groundwater and Surface Water Field Sampling and Analysis Plan* (Hydrometrics, 2010c), Surface water quality samples and surface water flow measurements were obtained from Prickly Pear Creek and Wilson Ditch. Water quality samples and water level measurements also were collected from Upper Lake and Lower Lake. The goal of the surface water quality investigation was to identify current contaminants and AOPC. While this section focuses on surface water quality, Section 8.3 addresses surface water hydrology, including streamflow and GWSWIs, as they relate to potential contaminant source areas and migration.

Surface water quality and flow measurement monitoring locations are shown in Figure 8-1. Locations used to assess GWSWIs between Upper Lake, Lower Lake, Prickly Pear Creek, and Wilson Ditch are shown in Figure 8-2 and discussed in Section 8.3.

8.2.1 Surface Water Sampling

Surface water data were collected in accordance with the *Phase II RFI Work Plan* (Hydrometrics, 2010a) and *Post-RI/FS Groundwater and Surface Water Field Sampling and Analysis Plan* (Hydrometrics, 2010c). Field and laboratory procedures and any significant deviations from the work plans are documented in Appendix 4-A. Supporting field documentation is provided in Appendix 8-B.

In 2010, surface water samples were collected as part of the semiannual monitoring program in July and November, the BERA sampling program in August 2010, and as supplemental sampling efforts at one location (Seep-10A) in June, and three gravel ponds located near Canyon Ferry Road in September. These sampling programs are discussed briefly below.

Semiannual surface water monitoring was conducted on July 8, 2010, and November 9, 2010. Surface water monitoring consisted of the collection of water quality samples, stage measurements, and discharge (streamflow) measurements at five sites on Prickly Pear Creek (PPC-3A, PPC-5, PPC-7, PPC-8, and PPC-103) and water quality samples and stage measurements at Upper Lake and Lower Lake. Sampling of Upper Lake was inadvertently omitted during the July monitoring event. During the November event, synoptic water quality samples also were collected from two piezometers (IP-102B and IP-103B) that are co-located with sampling stations PPC-102 and PPC-103 on Prickly Pear Creek. A list of the semiannual monitoring locations is provided in Table 8-1 and monitoring locations are shown in Figure 8-1.

The August 2010 BERA sampling events included collecting 33 surface water quality samples from Prickly Pear Creek, Upper Lake, Upper Lake Marsh, Lower Lake, Wilson Ditch, and several reference locations outside the Facility area. Data from the reference samples collected upstream on Prickly Pear Creek and from Walker Pond/Walker Creek are presented in the BERA report (Gradient, 2010b) and are not included in this Phase II RFI surface water evaluation. All other 2010 BERA surface water sampling locations and results are included in this discussion.

In November 2010, surface water samples were collected from three ponds associated with a gravel operation located north of the City of East Helena to evaluate whether selenium present in groundwater had affected surface water quality in the ponds. The location of the ponds and associated surface water sampling locations (Pond 1 through Pond 3) are shown in Figure 8-2.

Streamflow monitoring was conducted on Prickly Pear Creek and Wilson Ditch. Surface water monitoring on Prickly Pear Creek was conducted in a synoptic fashion. Five streamflow monitoring sites were sampled on Wilson Ditch. These locations include two previously established water quality sampling sites (WD-3 and WD-4) and three new sites located within and north of the EH-128/EH-132 area. Sites were sampled and streamflows measured from downstream to upstream in a single day, to provide information on flow gains and losses and in-stream parameter loading trends across various stream reaches, while minimizing the possibility of temporal variability. Streamflow monitoring results are discussed in Section 8.3.

8.2.2 Surface Water Quality Results

As discussed above, 2010 surface water quality monitoring events included semiannual sampling in July and November, extensive sampling in August 2010 to support the BERA, one sample collected at a seep observed along the northern edge of the slag pile (Seep-10A) in June, and three samples from gravel ponds located near Canyon Ferry Road.

Water quality samples were submitted to Energy Laboratories in Helena, Montana, for analyses of physical parameters, common constituents, and metals (dissolved, total and/or total recoverable). Phase II RFI metals data for surface water samples are compared with project SLVs in Table 8-2. Laboratory methodology and quality assurance/quality control procedures are further discussed in Appendix 4-A. Laboratory reports are provided in Appendix 8-C.

Available surface water data (1984-2010) were extracted from the project database and are provided in Appendix 8-D.¹¹ A metals screening table comparing historic analytical results to project SLVs is provided for reference in Appendix 8-E. All metal concentrations exceeding project SLVs are shaded in Appendix 8-E.

8.2.3 Surface Water Screening and Contaminants of Potential Concern

Project SLV exceedances were evaluated further for the combined 2010 surface water results. A summary of these statistics is presented in Table 8-3. Dissolved concentrations of arsenic, cadmium, iron, lead, selenium, and zinc were detected in one or more surface water sample locations at concentrations exceeding the project SLVs. The concentrations and detection frequencies were typically higher for total recoverable metals than for the dissolved metals. However, a similar list of COCs was identified by screening both sets of

¹¹ The data in Appendix 8-D include analytical results for dissolved, total, and total recoverable metals. There were additional samples in the database beyond what was documented as part of the Phase II RFI sampling events. Typically, these samples were collected during the time period that the BERA sampling was conducted.

data. In addition to the analytes mentioned above, aluminum, copper, silver¹², and thallium also had one or more detected concentrations that exceeded the project SLVs. The 10 COPCs identified in this screening analysis for 2010 surface water data are slightly different than previous screening level ecological risk assessments (SLERA), which identified the following metals as potential COPCs: antimony, arsenic, cadmium, copper, lead, manganese, mercury, selenium, thallium, and zinc (EPA, 2005; Gradient, 2010a).

The previous SLERAs and the BERA conducted metals screening on data collected between 2000 and 2010, rather than describing current conditions using the 2010 data. For risk characterization, the BERA evaluated surface water as a primary exposure pathway for aquatic life, and screened hardness dependent metals using a sample-specific hardness adjustment. Although dissolved surface water concentrations typically are analyzed for aquatic life, the MDEQ criteria are based on the total recoverable fraction and thus the BERA screened dissolved, total, and total recoverable fractions to the appropriate surface water benchmarks. These benchmarks varied by media and receptor, and thus are not always consistent with the project SLVs utilized in this document. The 2010 BERA identified metals with at least one historic concentration that exceeded the benchmark. Table 8-4 provides a side-by-side comparison of the COPCs identified in this Phase II RFI evaluation versus those identified in the BERA.

Given the objectives of the Phase II RFI, the dissolved phase surface water results are the most critical in evaluating contaminant migration from surface water to groundwater and the potential impacts to groundwater quality. The 2010 dissolved metals results are presented in Table 8-2 and the summary statistics are provided in Table 8-3. As mentioned previously, dissolved concentrations of arsenic, cadmium, iron, lead, selenium, and zinc were detected in one or more surface water sample locations at concentrations exceeding the project SLVs. Although it is recognized that additional COPCs were identified using the 2010 total recoverable fraction or historic surface water data, the 2010 dissolved COPCs are the focus of this Phase II RFI evaluation. The other analytes are discussed in detail in the BERA (Gradient, 2010a).

8.2.4 Distribution of Surface Water Contamination

Figures 8-3 to 8-7 depict contaminant distribution (analytical results by concentration ranges) within the Facility area for selected COPCs: arsenic, cadmium, copper, lead, and selenium.¹³ The distribution of these COPCs, which as a whole are considered representative of the distribution patterns for the remaining surface water COPCs, as summarized below (by surface water body):

- *Lower Lake:* Of the 10 potential COCs identified in surface water, arsenic, cadmium, copper, selenium, and thallium had one or more detections in Lower Lake that exceeded the associated SLV.
- *Upper Lake/Upper Lake Marsh:* Dissolved concentrations of cadmium, iron, lead, and zinc were detected above project SLVs in one or more samples collected from Upper

¹² It should be noted that silver was detected in one sample (from Upper Lake Marsh) and that the detection limit for silver (0.0005 mg/L) is greater than the project SLV.

¹³ Where multiple samples were collected at one sampling point, Figures 8-3 to 8-7 depict the highest concentration detected in samples from that location.

Lake or the Upper Lake Marsh. In addition, total recoverable aluminum, copper, and silver were detected above SLVs in one or more 2010 surface water samples. Of these metals, the BERA identifies cadmium, copper, and lead as the only analytes that exceed acute water quality criteria.

- *Prickly Pear Creek*: Dissolved arsenic and zinc were detected in one or more Prickly Pear Creek samples at concentrations greater than the project SLVs. While SLV exceedances in Prickly Pear Creek are contained to the reach adjacent to Lower Lake, arsenic and zinc are present at levels below SLVs are present both upstream downstream of this reach (Figure 8-3 and Figure 8-7). As discussed in the BERA, dissolved concentrations of arsenic, iron, lead, and manganese in Prickly Pear Creek were significantly higher adjacent to the Facility than at upstream reference locations. In contrast, copper and zinc concentrations were not significantly different between these locations.
- *Gravel Ponds*: The metals analyzed in the three pond samples (total recoverable arsenic and selenium) were not detected at concentrations greater than the project SLVs.
- *Wilson Ditch*: Cadmium was the only metal that was detected in Wilson Ditch at a concentration greater than the SLV. The only dissolved cadmium SLV exceedance in Wilson Ditch was observed in a sample collected north of Seaver Park in the northwestern portion of Lamping Field (Figure 8-4). Cadmium was not detected in Wilson Ditch south of Highway 12.
- *Seep*: In the sample from the seep (PPC-10A Area Seep) located on the north side of the slag pile, five of the eight total recoverable metals were detected at concentrations above project SLVs. These COPCs include arsenic, cadmium, copper, selenium, and zinc.

8.2.5 Areas of Potential Concern

As previous discussed, 10 metals analyzed in 2010 surface water samples from the Facility area were detected at concentrations greater than the project SLVs in one or more of the dissolved or total recoverable samples and therefore are identified as COPCs for surface water. Based on the distribution of the COPCs (Section 8.2.5), Upper Lake and Lower Lake and the portion of Prickly Peak Creek immediately adjacent to Lower Lake have been identified as the primary AOPCs for surface water. In particular, contaminant concentrations in samples collected from Upper Lake and/or Lower Lake, on either side of Tito Park were significantly elevated in arsenic, cadmium, lead, and selenium.

Based on the screening evaluation of the 2010 surface water results (Section 8.2.2), Wilson Ditch is not identified as an AOPC because dissolved COPC concentrations are generally less than project SLVs. One exception is the dissolved cadmium concentration (0.0007 mg/L) detected in sample WD-26, located in the northwestern portion of Lamping Field. However, because this concentration is greater than the concentrations observed in Wilson Ditch onsite and near Seaver Park, this concentration may not be related to the Facility and, therefore, this offsite area is not identified as an AOPC.

8.3 Groundwater/Surface Water Interactions Evaluation

As described in the *Phase II RFI Work Plan* (Hydrometrics, 2010a), the interactions between groundwater and surface water features in the project area, including Upper Lake/Upper Lake Marsh, Lower Lake, Prickly Pear Creek, and Wilson Ditch were evaluated as part of the Phase II RFI and BERA investigations. The objectives of the Phase II RFI (Hydrometrics, 2010a) GWSWIs evaluation were to:

- Quantify the direction and rate of flow between Prickly Pear Creek and the groundwater system adjacent to and north of the Facility.
- Identify areas of groundwater recharge and potential contaminant transport to Prickly Pear Creek.
- Evaluate the effect of seepage from Prickly Pear Creek on groundwater flow directions and plume migration directions and rates north of the Facility.
- Evaluate the effect of seepage from Wilson Ditch on groundwater flow directions and rates in Lamping Field and northward.
- Evaluate potential sources of arsenic in shallow groundwater in the southwest Lamping Field area.
- Provide information on leakage rates from Prickly Pear Creek and Wilson Ditch to the upper aquifer (or vice versa) for use in set up and calibration of the numerical groundwater flow model discussed in Section 12.

The evaluation of GWSWIs included synoptic surface flow measurements at select stations on Prickly Pear Creek and Wilson Ditch, and measurements of stream stage and groundwater elevations at gauging stations with co-located shallow piezometers and monitoring wells. Synoptic surface flow measurements also included measurement of tributary/outfall and diversion flows. Surface water monitoring locations are shown in Figure 8-1. Groundwater monitoring locations with select surface water stations are shown in Figure 8-2.

Synoptic and continuous water level measurements were used to assess lateral and vertical gradients and temporal water level patterns that would indicate potential exchange between surface water features and groundwater. The objective of synoptic flow measurements was to identify losing and gaining reaches of Prickly Pear Creek and Wilson Ditch, and quantify exchanges between these features and groundwater. Continuous water level measurements provide information regarding the degree of connection between surface water and groundwater. Data collection activities completed to evaluate GWSWIs in the vicinity of Prickly Pear Creek and Wilson Ditch included the following:

Prickly Pear Creek

- Synoptic surface flow measurements were completed at 14 stations on Prickly Pear Creek and 6 diversions or tributaries/outfalls to the creek. Synoptic measurements were completed at all stations on December 1, 2009, and August 3 and 4, 2010. Synoptic flow measurement events were completed on two other occasions with a lesser number of stations: once in November 2011 as part of the Post-RI/FS monitoring described above, and once in July.
- Synoptic groundwater and surface water level measurements were completed in June and October at select surface water station locations. A complete synoptic water level measurement event, including select stations with co-located stream gauges, shallow piezometers, and monitoring wells, was completed in November 2010. Stage elevations for Upper Lake and Lower Lake also were measured to assess potential flow directions and interactions between the lakes, Prickly Pear Creek, and groundwater. Groundwater elevation contour maps based on June and October 2010 synoptic water level measurement events are presented in Figures 8-8 and 8-9.
- Continuous and periodic manual water level data were collected from select monitoring wells, surface water stations, and piezometers over part or all of the Phase II RFI activities.

Wilson Ditch

- Synoptic surface flow measurements were completed at five stations on Wilson Ditch on June 14, 2010, and October 10, 2010, while the ditch was operated during the period between May 17 and August 30, 2010.
- Wilson Ditch was briefly operated again after the end of irrigation season between October 19 and November 9, 2010, at an estimated rate of 1 to 1.5 cfs to observe water level responses in nearby monitoring wells and shallow piezometers.
- Continuous and/or manual water level measurements were collected from select piezometers and monitoring wells near Wilson Ditch.

Surface and groundwater level monitoring locations are listed in Table 8-5 and shown in Figures 8-1 and 8-2. Table 8-6 and Appendix 8-F present August 2010 streamflow measurements. Figures 8-8 through 8-10 illustrate groundwater elevation contours and the results of synoptic streamflow measurements to assess gaining and losing reaches of Prickly Pear Creek and Wilson Ditch. Descriptions of the GWSWI monitoring activities and methodologies (including those for piezometer installation, transducer data collection, and field water measurement) are included in Appendix 4-A. Hydrometrics' field notes and photo logs compiled during these sampling activities are included in Appendix 8-B. Hydrographs for monitoring sites are included as Figures 8-11 to 8-17. The data used to compile the hydrographs are included in Appendix 8-G. The results of assessment of interactions between each surface water feature and groundwater are summarized below.

8.3.1 Upper Lake/Lower Lake

Potentiometric surface maps and temporal water level data from the Phase II RFI confirm conclusions from prior investigations that Upper Lake and Lower Lake are significant sources of recharge to groundwater flow systems under the Facility. Figures 8-8 through

8-12 show spatial and temporal relationships between water levels in the lakes, groundwater, and Prickly Pear Creek that control surface water/groundwater exchanges. Specific observations based on these data are summarized below:

- Collectively, both Upper Lake and Lower Lake serve as constant head sources of recharge to the Upper Aquifer.
- Upper Lake stage levels are consistently 1 to 2 feet higher than Lower Lake and groundwater levels (Figure 8-11) in northerly, northwesterly, and westerly directions (Figures 8-8 and 8-9).
- Consistent stage differences between Upper Lake and Lower Lake define a gradient that directs recharge to shallow groundwater from Upper Lake in a northerly direction under Tito Park toward Lower Lake and northwesterly toward the former Acid Plant and the Facility.
- The close correlation in water level trends and relative water levels between DH-3 and Upper Lake indicates that the lake recharges groundwater in a westerly direction and may provide significant recharge and driving head to older Tertiary sediments that form the Deeper Groundwater System beneath the Facility, as well as in the alluvial sediments of the Upper Aquifer.
- The effect of Upper Lake on groundwater flow toward Prickly Pear Creek is less well defined, but lake stages are higher than stream stages and shallow groundwater levels northeast of the lake suggesting that a component of flow from the lake is directed back toward the creek.
- Recharge to shallow groundwater from Lower Lake flows toward and discharges to Prickly Pear Creek northeast of Lower Lake (Figures 8-8 and 8-9).

8.3.2 Prickly Pear Creek

Maximum flows of 346 cfs (PPC-8) and 412 cfs (PPC-7) measured in Prickly Pear Creek during the Phase II RFI occurred during the July 2010 event. Flow measurements were not obtained at the other stations during this event because of extreme stage levels. Excluding the July 2010 event, a maximum flow of 81.5 cfs was recorded during the August 2010 event upstream of the Facility (SG-02) before the diversion to Upper Lake. The minimum flow of 32.8 cfs was recorded at SG-02 during the December 2009 event.

Except for a relatively short stretch on the east side of the Facility and downgradient from Lower Lake, Prickly Pear Creek is predominantly a losing stream between the marshes south of Upper Lake and Canyon Ferry Road. The net measured flux to the Upper Aquifer between Upper Lake and Canyon Ferry Road in August 2010 was approximately 25 cfs. Net measured surface water loss to groundwater in August 2010 downstream of the north end of the Facility was more than 17 cfs. Groundwater equipotential lines in Figures 8-8 and 8-9 show the effects of groundwater mounding consistent with recharging conditions along this reach of the creek. Observations of data indicating the nature of interactions between Prickly Pear Creek and groundwater include:

- Synoptic streamflow measurements indicate that Prickly Pear Creek transitions from a gaining stream south of Upper Lake to a losing stream adjacent to the lake and

marsh area (Figure 8-10). This transition roughly coincides with where the creek exits the canyon in the foothills and onto the valley-fill sediments.

- Further downstream, streamflow measurements indicate that Prickly Pear Creek gains within Reaches 4 and 5 on the east side of the Facility, from Lower Lake to station PPC-33 (Figure 8-10). Groundwater originating from Lower Lake may discharge to the creek within these reaches. Hydrographs for co-located stream gauges and piezometers at PPC-102 and PPC-103 indicate a slightly downward gradient between the creek and shallow groundwater at the upper end of Reach 4 (Figures 8-11 and 8-12), suggesting that the transition from losing to gaining conditions in the creek actually may occur part way down Reach 4, below PPC-102 and PPC-103 (Figure 8-10). The location of the transition from losing to gaining is important for evaluation of transport of contaminants from Lower Lake to groundwater and Prickly Pear Creek.
- Streamflow measurements indicate that Prickly Pear Creek transitions back to a losing stream downstream of station PPC-33 (Figure 8-10). While many of the losses measured along successive reaches are generally within the range of measurement error for synoptic streamflow measurements, water level data at surface water measurement stations with co-located piezometers or monitoring wells generally confirm downward gradients exist between the stream and shallow groundwater, suggesting that the creek is losing water to the Upper Aquifer downstream of PPC-33 (Figures 8-13a and b). These stream losses increase in magnitude downstream of the City of East Helena.
- Seasonal recharge effects on the Upper Aquifer are illustrated by hydrographs for piezometers and monitoring wells located in the vicinity of Prickly Pear Creek (Figure 8-14). These wells show water level rises of 2 to 10 feet beginning in mid-May and peaking in June and early July, coincident with peak stages and flows on the creek.

8.3.3 Wilson Ditch

Wilson Ditch conveys water from Upper Lake to irrigate pasture and hay crop north and west of Lamping Field. Wilson Ditch is contained within a pipe between Upper Lake and the western Facility property boundary, where it daylight into an open and unlined irrigation canal. Wilson Ditch water flow measurements in June 2010 recorded 4.01 cfs flowing in the ditch at the upstream end (WD-2) and 2.57 cfs flowing in downstream reach of the ditch (WD-26). In August 2010, the upstream flow was recorded at 3.78 cfs and the downstream flow was recorded as negligible (0.003 cfs); this decrease in flow was caused by a major diversion in the lower half of the ditch at the time of the August 2010 measurements. Peak flows in the ditch in the spring are typically 7 to 8 cfs. The following observations were derived from evaluation of the relationships between Wilson Ditch and groundwater:

- Leakage from Wilson Ditch provides recharge to groundwater during the irrigation season. Mounding in shallow groundwater is apparent during the summer, particularly the upper portion of the ditch shown in Figure 8-8, whereas mounding dissipates during the off season when the canal is shut off (Figure 8-9) and appears to have little effect on groundwater flow.

- Net surface flow losses to groundwater in Wilson Ditch estimated from measurements during June and August 2010 synoptic flow measurement events ranged between 0.6 (August) and 1.4 cfs (June). These two loss estimates are not directly comparable; the August estimates encompassed a shorter reach of the ditch because of an irrigation diversion between measurement stations.
- Groundwater levels in monitoring wells and piezometers located in the vicinity of Wilson Ditch directly responded to infiltration from the ditch. Groundwater level increases of more than 10 feet were recorded in EH-132, and hydrographs of wells proximal to the ditch show clear responses to fluctuations in ditch flows because of varying irrigation demands during the summer of 2010 (Figure 8-15).
- Groundwater levels in select piezometers and wells monitored during the October/November 2010 ditch flow test recorded rapid increases because of infiltration from Wilson Ditch flows (Figure 8-16). Co-located Upper Aquifer (EH-205) and Deeper Groundwater System (EH-210) monitoring wells, which were instrumented for the ditch flow test, both recorded a response during the test, indicating that the Deeper Groundwater System is influenced by infiltration from the ditch, although to a lesser degree than the Upper Aquifer. The response to the ditch test in the EH-205/EH-210 cluster also shows that the mounding caused by infiltration from the ditch reverses the gradient between the Upper Aquifer and Deeper Groundwater System from upward to downward.

8.3.4 Groundwater Flow

Groundwater level trends in wells located on and downgradient of the Facility between Wilson Ditch and Prickly Pear Creek are influenced by spring runoff; however, the timing, rate, and magnitude of the increase varies greatly compared with the wells in proximity to surface water (Figure 8-17). Water levels in these wells show a lag in response to recharge with peaks generally occurring in August, approximately 2 months after the responses in wells proximal to Wilson Ditch and Prickly Pear Creek.

8.3.5 Groundwater and Surface Water Quality Comparison

Concentrations of select water quality analytes for groundwater and surface water monitoring stations were plotted on maps to evaluate for consistency with physical interactions observations. The water quality data maps are provided in Figures 8-18 through 8-26. Supporting information is presented in Appendix 8-H. The following are conclusions:

- Elevated concentrations of several analytes, including sulfate and arsenic present in Lower Lake and in groundwater samples, also are present in Prickly Pear Creek within the gaining reach of the creek downstream of the dam. Subsurface transport of contaminants, such as arsenic, and discharge to the creek in this area is consistent with hydrologic data indicating that groundwater recharged from Lower Lake discharges to the creek along this reach.
- Elevated concentrations of several analytes, including arsenic, selenium and sulfate, are present in groundwater adjacent to Prickly Pear Creek on the north side of the slag pile, including in the seep at PPC-10a. This reach of the creek is losing overall,

and concentrations of these analytes in surface water are either not detected or are similar to upstream concentrations because groundwater is not discharging to the creek and discharges from the seep are not sufficient to elevate concentrations in the stream.

8.4 Contaminant Fate and Transport

Contaminants in surface water potentially could infiltrate into groundwater, accumulate in sediments, be transported with surface water in Prickly Pear Creek or Wilson Ditch, and be taken up by a receptor (human or ecological). The main transport mechanisms for surface water in the Facility area are likely downstream flow and infiltration to groundwater. A more detailed discussion of contaminant fate and transport mechanisms related to surface water is presented in Section 11.

Contaminants in surface water in Upper Lake/Upper Lake Marsh may migrate via surface water flow from the lake to Prickly Pear Creek and seasonal discharges (during irrigation season) to Wilson Ditch, and be carried downstream with surface flow. Contaminants in Wilson Ditch discharges may be distributed to agricultural land irrigated with water from the ditch. Surface water contaminants also may migrate from surface water to groundwater via subsurface leakage from Upper Lake/Upper Lake Marsh, Lower Lake, Wilson Ditch and Prickly Pear Creek. Discharges from the HDS water treatment facility into Lower Lake represent a possible mechanism for metals to be transported into Lower Lake.

Metals in surface water can be transferred to sediment through adsorption. The sediment may accumulate at the bottom of the standing water bodies or may be transported further downstream in the flowing water bodies during flow events with sufficient energy to entrain sediment. Unique to Wilson Ditch is that the ditch is dry during some portions of the year and accumulated sediment then is exposed to another set of transport mechanisms, such as wind or uptake by terrestrial receptors. These additional transport mechanisms are likely to be minimal compared to downstream flow and infiltration to groundwater.

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9 Sediment

Sediment is present in surface water bodies located on and near the Facility, including Prickly Pear Creek, Upper Lake, Upper Lake Marsh, Lower Lake, and Wilson Ditch. Remedial activities were conducted in the early and mid-1990s in Lower Lake and Wilson Ditch and following the plant closure in 2001. Consequently, the current nature and extent of sediment contamination is improved from past conditions. Sediment sampling was conducted as part of the 2010 BERA to evaluate current sediment conditions at the Facility. Results of the 2010 sediment sampling are presented in the BERA report (Gradient, 2010b) and are evaluated in this section with respect to the objectives of the Phase II RFI.

9.1 Summary of Previous Investigations

As summarized in Section 2.3.4, previous investigations at the Facility included sediment sampling. Sediment samples were collected and analyzed for metals as part of the 1991/1992 investigation of Prickly Pear Creek (USFWS, 1997) and the 2003 *Supplemental Ecological Risk Investigation* (EPA, 2005). The results from this work were incorporated into the BERA data analysis (and are discussed below). Previous sampling data of Prickly Pear Creek sediment in 1991 and 1992 collected by the U.S. Fish and Wildlife Service (USFWS) are used only for historical reference in the BERA. The BERA report (Gradient, 2010b) presents a table summarizing the 1991/1992 data; this table (Table 2.9 in the BERA report) is included in Appendix 9-A of this Phase II RFI report. Appendix 9-A also includes data tables from the BERA that incorporate the 2003 sediment sampling results.

Sediment sampling also was conducted in conjunction with the Wilson Ditch and Lower Lake sediment removal activities in the mid-1990s. Sediment was removed from the bottom and sides of Wilson Ditch downstream of the Facility from locations WD-2 to WD-3 (see Figure 9-1). The sediment sampling results associated with these remedial activities are not incorporated into the BERA or Phase II RFI sediment evaluations.

9.2 Phase II RFI Investigation

9.2.1 Sediment Sampling and Analysis

Sediment samples were collected in August 2010 from Prickly Pear Creek (eight reference samples from upstream of the Facility, and eight characterization samples from adjacent to or downstream of the Facility), Upper Lake Marsh (nine samples), Upper Lake (five samples), Lower Lake (five samples), and Wilson Ditch (five samples). The 2010 sediment sample locations are shown in Figure 9-1. Sediment sampling methodology is described in the BERA work plan (Gradient, 2010a).

The sediment samples were submitted to Energy Laboratories in Helena, Montana, for analysis. Samples were analyzed for conventional parameters (pH, total organic carbon, moisture, and grain size fraction) and for total metals (aluminum, antimony, arsenic,

barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, selenium, silver, thallium, vanadium, and zinc).

Field notes from the August 2010 sediment sampling activities are included in Appendix 9-A. The laboratory data reports for the 2010 samples are provided in Appendix 9-B.

9.2.2 Results

Results for the sediment sample collected in 2010 are summarized in Table 9-1. Sediment samples were analyzed for aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, vanadium, and zinc. All of the metals analyzed, except beryllium, barium, and thallium, were detected in every 2010 sediment samples; beryllium was not detected in any of the samples, barium was detected in 17 samples, and thallium was detected in 11 samples. Results for selected metals (antimony, arsenic, cadmium, copper, lead, manganese, mercury, silver, and zinc) are also shown in Figures 9-2 through 9-10.

The BERA analyses of potential risks to ecological receptors included historic analytical data from the 2003 sediment samples from Lower Lake, Upper Lake Marsh, and Prickly Pear Creek. For Lower Lake and Prickly Pear Creek, the 2003 metals concentrations are approximately an order of magnitude greater than the 2010 metals concentrations at similar locations (2003 data is summarized in Appendix 9-A). For Upper Lake Marsh, metals concentrations in the 2010 dataset are lower than in the 2003 dataset, but not by a consistent factor (Gradient, 2010b).

Metals concentrations are generally consistent in 2010 Prickly Pear Creek sediment samples, including the upstream reference locations. The BERA report concludes that onsite sediment concentrations in Prickly Pear Creek are not significantly greater than at upstream reference locations (Gradient, 2010b).

9.3 Sediment Contaminant Distribution and Screening

The metals concentrations detected in the 2010 sediment samples are screened against the project SLVs (see Section 4) in Table 9-1. Metals that were detected at concentrations greater than the corresponding SLVs (shaded values in Table 9-1) are summarized below by sampling area. Figure 9-2 shows the locations of sediment samples collected in 2010. Distribution (in terms of detected concentration ranges) of the sediment COPCs in the 2010 sediment samples is shown in Figures 9-3 through 9-10¹⁴ and discussed below. Figure 9-2 shows the locations of sediment samples collected in 2010.

9.3.1 Lower Lake

Antimony, arsenic, cadmium, copper, lead, manganese, mercury, silver, and zinc were detected at concentrations above project SLVs and background concentrations in the Lower Lake sediment samples (labeled as LL-xx-SED). The cadmium concentrations exceeded the SLV by approximately 100 to 1,000 times. Lead and mercury concentrations exceeded their respective SLVs by about 350 times. Antimony, arsenic, copper, silver, and zinc concentrations were generally less than 100 times their respective SLVs or background

¹⁴ Reference sample locations are not shown on Figures 9-2 through 9-10.

concentrations. In general, higher metal concentrations were detected on the northern side of Lower Lake.

9.3.2 Upper Lake and Upper Lake Marsh

Antimony, arsenic, cadmium, copper, lead, mercury, silver, and zinc were detected in all of the Upper Lake sediment samples (labeled as UL-xx-SED or ULM-xx-SED) at concentrations above project SLVs, and manganese concentrations exceed the SLV in multiple samples. In general, the highest metals concentrations were detected in the samples in the northwest corner of Upper Lake and near Tito Park. The highest concentrations were detected in sample, UL-23-SED, located on the western shore of the lake.

In the Upper Lake Marsh samples, antimony, arsenic, cadmium, copper, lead, manganese, mercury, silver, and zinc were detected in one or more of the samples at concentrations greater than the project SLVs. In general, the highest metals concentrations detected in these samples are associated with sample locations ULM-3, ULM-4, and ULM-6, located along the southeastern shore of Upper Lake. Lead and mercury concentrations are both 100 to 1,000 times higher than background concentrations or their SLVs throughout most of this area.

9.3.3 Prickly Pear Creek

Arsenic, cadmium, copper, lead, manganese, mercury, silver, and zinc were detected in one or more of the 2010 Prickly Pear Creek samples (labeled as PPC-xx-SED) at concentrations above project SLVs. Concentrations are generally less than 10 times SLV or background concentrations.

Concentrations in Prickly Pear Creek reference samples (labeled as REF-PPC-XX-SED) collected upstream of the Facility detected antimony, arsenic, cadmium, lead, and zinc at concentrations above project SLVs in all of the samples; manganese concentrations exceed the SLV in seven samples; and copper and silver concentrations exceed the SLVs in one sample.

9.3.4 Wilson Ditch

Arsenic, cadmium, copper, lead, manganese, mercury, silver, and zinc were detected at concentrations greater than project SLVs in all of the Wilson Ditch sediment samples (labeled as WD-X-SED). Antimony, arsenic, cadmium, manganese, silver, and zinc concentrations exceeded their respective SLVs by less than 10 times. Lead and mercury concentrations exceed background or SLV concentrations up to about 1,100 and 650 times, respectively; both metals are elevation from the point of discharge from the buried pipe through the Manlove neighborhood.

Backfill placed in the ditch after the 1993 sediment remedial action was reported to contain less than 200 mg/Kg of lead and less than 100 mg/Kg of arsenic (Hydrometrics, 1999a). While arsenic was detected at concentrations below 100 mg/Kg in all of the 2010 sediment samples collected from Wilson Ditch, lead was detected in the samples at concentrations ranging from 320 mg/Kg to 1,610 mg/Kg.

9.4 Contaminants of Potential Concern

Antimony, arsenic, cadmium, copper, lead, manganese, mercury, silver, and zinc are identified as COPCs for sediment based on screening of the 2010 sediment data relative to project SLVs. The sediment COPCs are the same contaminants¹⁵ that are identified in the BERA report as occurring in Facility-area sediments at concentrations greater than the threshold effects concentrations for benthic invertebrates (Gradient, 2010b).

9.5 Contaminant Fate and Transport

The following section discusses fate and transport mechanisms for the contaminants in sediment. Potential contaminant transport mechanisms include: particulate transport by surface water flowing (i.e., suspended load); erosion of sediments or buried sediments during flood events; leaching of contaminants from sediment into groundwater or surface water, and/or uptake by a receptor (human or ecological).

Seasonal high-water events may scour sediments and transport particulates as a suspended load along the creek or ditch channels. The affected sediment will be redistributed and deposited downstream. For example, during flood events, water flowing through Prickly Pear Creek may be diverted to Upper Lake, and suspended sediment in the flow deposited in Upper Lake.

Sediment contaminants have the potential to leach and affect groundwater or surface water quality. This includes suspended sediment in surface water bodies, areas where sediment is deposited and subject to seasonal moisture (e.g., ditch bottoms, flood plains, and the marsh) and sediment located in stormwater features in the upland portion of the Facility. Leaching of metals from sediments in permanent water bodies (e.g., Lower Lake) potentially may act as continuing sources of contaminants to groundwater and/or surface water.

Contaminant leaching from sediment and subsequent migration to groundwater is discussed in Section 11.

9.6 Areas of Potential Concern

Lower Lake and Upper Lake are identified as AOPC based on the distribution of sediment contaminant concentrations exceeding project SLV and background concentrations. The open-ditch portion of Wilson Ditch west of the Facility also is an AOPC because of elevated sediment concentrations of lead and mercury in the Manlove neighborhood.

¹⁵ The BERA also identified nickel as a contaminant of potential concern.

10 Stormwater

Much of the ground surface at former Facility currently is covered with impervious surfaces, including concrete, asphalt, and temporary synthetic liners. As a result, the capacity for rainfall and snowmelt to infiltrate into the subsurface is relatively low, and stormwater runoff relatively high. The stormwater collection and conveyance system consists of a series of interconnected catch basins that capture runoff and divert it to either the Containment Facility (rodeo grounds storage tank), located west of the Facility, or to the Thornock Tank. Stormwater from these storage tanks is subsequently conveyed to the HDS water treatment facility¹⁶ for treatment. Treated stormwater is discharged to Lower Lake under the facility MPDES permit.

10.1 Summary of Previous Investigations

The CC/RA report (Hydrometrics, 1999a) summarizes historical stormwater quality information before the 1997 installation of the current stormwater collection and conveyance system described above. A summary of water quality from 1994-1997 is included in Appendix 10-A.

10.2 Phase II RFI Investigation

The May 2010 stormwater sampling event was conducted concurrent with the preparation of the Phase II RFI Monitoring Work Plan. Stormwater drainage basins, before recent demolition activities, are identified in Figure 1 (provided in Appendix 10-B) of the Facility's 2006 Stormwater Pollution Prevention Plan (SWPPP). Thirty drainage basins are described in the SWPPP. Stormwater samples were collected from 5 of the 30 basins (Basins 12, 13, 15, 16, and 27) suspected to contain contaminant source areas. The sources include several former onsite rail corridors and the Lower Ore Storage Area. The stormwater sampling plan (Hydrometrics, 2010c) is included in Appendix 10-C.

The containment facility sump in Basin 27 was identified for sampling because it integrates all site stormwater immediately before treatment. Consequently, the concentrations in this sump provide a baseline for evaluating stormwater quality at individual potential source areas. Stormwater in potential source areas with concentrations greater than those present in the containment facility sump are implied source areas. Stormwater sampling documentation is included in Appendix 10-C (e.g., sampling notes, photographs). Laboratory data sheets are provided in Appendix 10-D.

Stormwater samples were collected at the outfalls of five Facility site drainage areas (as defined in the Facility's 2006 SWPPP), and from subdrainage areas within the major drainages. Seventeen stormwater samples were collected from catch basins (sumps), stormwater conveyance pipes, or, in some cases, from areas of concentrated overland flow. Nine of the samples represent main sumps or stormwater collections points, and the

¹⁶ The HDS water treatment facility was modified following Facility closure for stormwater treatment.

remaining eight samples represent subareas draining to these main sample points. The field sampling methodology is presented in Appendix 4-A. A photo log of the sampling event is included in Appendix 10-C.

The samples collected were submitted to Energy Laboratories in Helena, Montana, for analysis of TSS; pH; and total recoverable arsenic, selenium, cadmium, copper, iron, lead, and zinc. The 2010 stormwater analytical results are shown in Table 10-1 and sample locations are shown in Figure 10-1. HDS effluent and Lower Lake sample data collected as part of the HDS sampling are included in Appendix 10-E for selenium and sulfate. A comparison of these stormwater sampling results to the average results from 1994 to 1997 (Appendix 10-A) indicates stormwater quality runoff has improved at the Facility.

As part of the stormwater investigation, METG HDS effluent data were reviewed (Appendix 10-E). The information included HDS discharge effluent data for sulfate extending back to 1994. Sulfate concentrations have ranged from 130 mg/L to 3,499 mg/L during this period. Selenium concentration data are less frequent, with one data point in 1998 and more frequent data between 2007 and 2010. From 1998 to 2010, the selenium daily maximum has ranged between 0.061 mg/L and 2.4 mg/L.

10.3 Stormwater Screening

May 2010 stormwater concentrations were compared with project screening values (Table 4-2). All samples analyzed exceeded project SLV values for arsenic, cadmium, and lead. Copper and selenium concentrations exceeded the project screening value in one sample from the Ore Storage Yard. Concentrations and project SLV exceedances are noted in Table 10-1. Based on this limited screening, arsenic, cadmium, lead, copper, and selenium were identified as COPCs in stormwater.

HDS effluent selenium concentrations continuously exceeded the project SLV for selenium before the Facility closed in 2001. Between 2001 and the end of 2010, selenium concentrations exceeded the project stormwater SLV in 13 of 66 samples. Most of these exceedances were in the fall/winter of 2009. The most recent exceedance was in May 2010.

10.4 Distribution of Stormwater Contamination

In those basins sampled, the analytical results identify the combined runoff from the soil and concrete area of the Ore Storage Yard (Basin 15/Thawhouse Gate Sump) as the primary source of metals in stormwater runoff. Stormwater in this basin includes runoff from the Baghouse Sump (sample EHSW-1005-103), the Scale House Sump (sample EHSW-1005-104), the railroad tracks on the west side of the Thawhouse (sample EHSW-1005-110), and the Ore Storage Yard area (sample EHSW-1005-114). All of this stormwater collects in the Thawhouse Gate Sump, which also was sampled (sample EHSW-1005-111). Within this basin, the Ore Storage Yard area sample (EHSW-1005-114) had the highest metals concentrations. The sample collected from Basin 12 (EHSW-1005-109), which represents runoff that collects from the east side of the CSHB, also is potentially a source of metals.

The sample (EHSW-1005-115) from the sump by the water treatment facility (Basin 13) and the sample (EHSW-1005-106) from the Sinter Facility Sump (Basin 12) had the lowest

detected metal concentrations. Three metal concentrations (arsenic, cadmium, and lead) exceed the project SLVs.

2010 DMR data, presented in Appendix 10-E, provide concentrations of permit-required metals analyses. These concentrations indicate permit limits are met.

10.5 Contaminant Fate and Transport

During storm events, stormwater is transported via overland flow to the Facility's stormwater conveyance system (e.g., open ditches and pipes), evaporates, or directly infiltrates into site soils. Stormwater infiltrating into site soils may transport contaminants and/or leach contaminants in site soils and eventually adversely affect groundwater quality beneath the site or contaminants may be attenuated by soil filtration or adsorption. Stormwater collected by the Facility's stormwater system for treatment is subsequently discharged to Lower Lake. Contaminants discharged to Lower Lake (i.e., HDS effluent water) may accumulate in lake sediment, infiltrate through subsurface soils and/or leach underlying sediment/soil and affect groundwater quality. These migration pathways are discussed further in Section 11.

10.6 Areas of Potential Concern

Recent data indicate that current HDS effluent discharges to Lower Lake contain selenium concentrations above project screening levels for the protection of groundwater. Therefore, these discharges are considered a potential source (i.e., AOPC) of selenium to sediment and groundwater.

Analytical results confirmed elevated concentrations of arsenic, cadmium, copper, lead, and selenium in stormwater runoff from the Ore Storage Yard. This area is considered a potential source area contributing to stormwater contamination. Stormwater flows from this area have not been measured and, therefore, loads from this area to the HDS effluent are not known. Other source areas also were identified, including the Baghouse Sump, railroad tracks on the west side of the Thawhouse, and the Thawhouse Gate Sump. These areas are considered lower priority with respect to loading to the treatment system because the concentrations of metals in stormwater from these areas were significantly less than measured at the Ore Storage Yard. Concentrations detected in these areas were generally equal to or slightly greater than the Containment Facility Tank sample. An analysis of flow from the various stormwater basins would be required to further quantify and isolate the loading to the treatment system.

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11 Contaminant Fate and Transport

The section focuses on the fate and transport of arsenic and selenium in groundwater. Section 11.1 summarizes the results of previous investigations conducted to delineate the nature, extent, and mobility of the arsenic and selenium groundwater plumes. Section 11.2 discusses the results of Phase II RFI site investigations designed to further characterize ongoing sources and geochemical factors affecting mobility. Finally, Sections 11.3 through 11.5 update the site conceptual models of groundwater geochemistry, arsenic transport, and selenium transport, respectively.

11.1 Summary of Previous Investigations

The following discussion review previous CSMs developed before the Phase II RFI. Section 11.1.1 discusses potential routes of migration of contaminants with an emphasis on groundwater transport pathways. Section 11.1.2 assesses potential sources of groundwater contamination and identifies data gaps addressed by the Phase II RFI. Section 11.1.3 reviews the environmental chemistry of arsenic and selenium. Finally, Section 11.1.4 describes how site geochemistry affects arsenic and selenium transport in groundwater.

11.1.1 Potential Routes of Contaminant Migration

Previous investigations of the Facility have shown that surface and subsurface soils contain contaminant concentrations that exceed human health and ecological screening levels. This list of contaminants includes arsenic, cadmium, copper, lead, and zinc (Hydrometrics, 1999a; ACI, 2005). Additionally, arsenic and selenium have been identified as COCs in groundwater, based on reported concentrations that exceed primary MCLs in areas downgradient of the Facility (Hydrometrics, 2010a).

As discussed in the CC/RA report (Hydrometrics, 1999a), contaminants present in one environmental media potentially can be mobilized and contribute to the contamination of another. The primary pathways for contaminant migration at the Facility identified by Hydrometrics (1999a) are shown in Figure 11-1. Of the potential pathways identified in Figure 11-1, site soil, and groundwater and surface water pathways are briefly reviewed below (slag also is discussed in Section 11.1.1.2). Although air emissions pathways to offsite receptors were historically significant, this pathway was previously addressed as part of EPA's CERCLA and National Ambient Air Quality Standard programs.

11.1.1.1 Process Water Ponds to Groundwater

The principal cause of elevated contaminant concentrations in groundwater is attributed to historical seepage from process ponds and losses from process water circuits (Hydrometrics, 1990 and 2010a). Included in these losses are fluids from the former Speiss Pond and Pit, and from the Acid Plant Water Treatment Facility and its associated drying areas (Figure 2-3). Also included is water from the main plant water circuit that terminated at Lower Lake (an unlined manmade feature); where water either evaporates or infiltrates into the subsurface. According to the CC/RA report (Hydrometrics, 1999a), arsenic concentrations

greater than 250 mg/L occurred in Lower Lake before the isolation of the Speiss Granulation Circuit in 1984, and in lesser concentrations thereafter. Ongoing process water loading to groundwater currently is provided by infiltration from Lower Lake, which receives treated stormwater from the Facility's HDS plant. Following termination of Facility operations in April 2001, reported concentrations of arsenic and selenium in Lower Lake have ranged from 0.041 to 0.243 mg/L and 0.016 to 0.042 mg/L, respectively. Phase II RFI sediment sampling was conducted in Lower Lake in part to understand if underlying sediment (through which process water flows) is a potential source of contaminants to groundwater (Hydrometrics, 2010a). Phase II RFI sediment results are presented in Section 9 and current conditions are described in Sections 11.2 through 11.5.

11.1.1.2 Soil to Groundwater Pathway

As discussed in the *Phase I RFI* (ACI, 2005) and *Phase II RFI Work Plan* (Hydrometrics, 2010a), arsenic- and selenium-bearing soils are present at the Facility both above (i.e., unsaturated) and below (i.e., saturated) the water table. Contaminants within the soil vadose zone are potentially liberated into infiltrating surface water (from exposed areas of the site) and/or leaking water from subsurface lines by dissolution/desorption reactions. Below the water table, soil-bound arsenic and selenium may be mobilized by direct contact with groundwater.

Leaching of slag along the northern and eastern property lines (Figure 2-3) also was identified as a potential pathway to groundwater (GSI, 2011). Leaching tests conducted during the CERCLA *Comprehensive RI/FS* reported a range of arsenic concentrations in leachate between 0.02 and 0.59 mg/L (Hydrometrics, 1990), and EPA (2010b) reported slag leachate concentrations for arsenic and selenium of 0.028 to 0.252 mg/L and 0.002 to 0.050 mg/L, respectively. The importance of slag as a source depends on the amount of infiltration that actually reaches groundwater. The 1990 *Comprehensive RI/FS* report (Hydrometrics, 1990) estimated net infiltration to be highly variable, from -45 percent (net evaporation exceeding infiltration) to 62 percent of total rainfall infiltrating the slag test pits. The presence of solidified layers with low or fracture-controlled permeability in the slag was not considered in these estimates.

As part of the Phase II RFI, additional surface soil, subsurface soil, and slag samples were collected and analyzed for metals concentrations to further delineate the nature and extent of contamination in source areas (Hydrometrics, 2010a). Leaching and sequential extraction tests also were conducted to assess the relative availability of the different chemical forms of arsenic and selenium. Finally, three wells (DH-74, DH-75, and DH-76) were drilled through the slag pile to evaluate groundwater quality beneath the slag and to determine the flow and geochemical vertical gradients (through paired wells DH-74 and DH-75) in this area. Phase II RFI soil and soil leaching results are presented in Section 6 and current conditions are described in Sections 11.2 through 11.5.

11.1.1.3 Groundwater to Surface Water Pathway

Contaminants derived from historical Facility activities are present in groundwater beneath the site. Based on hydrogeologic information, the direction of groundwater flow is generally to the north and northwest. However, local groundwater flow to Prickly Pear Creek (the primary surface water resource in the vicinity of the Facility) occurs as seepage from Lower Lake through the earthen berm that separates the Lower Lake and creek. As a result, there

is a component of groundwater flow on the northeast side of Lower Lake that flows toward Prickly Pear Creek. According to the *Phase I RFI* report (ACI, 2005), there appears to be little groundwater contribution to Prickly Pear Creek north of Lower Lake.

11.1.1.4 Surface Water to Groundwater Pathway

Streamflow losses provide a potential pathway for transport of contaminants from surface water to groundwater. According to the *Phase I RFI* report (ACI, 2005), potential losses from Prickly Pear Creek to groundwater in the vicinity of the Facility are of small enough magnitude to be within flow measurement errors (and thus cannot be quantified); however, monitoring wells north of Facility show evidence of seasonal groundwater chemistry and water level elevation changes resulting from seasonal recharge of groundwater from Prickly Pear Creek. Because contaminant concentrations in Prickly Pear Creek are less than concentrations in groundwater, it has been assumed that the creek is not an important source or pathway of contaminant loading to groundwater. Phase II RFI sediment sampling also was conducted in Prickly Pear Creek to understand if underlying sediment is a potential source (Hydrometrics, 2010a). Phase II RFI surface water and sediment results are presented in Sections 8 and 9, respectively; current conditions are described in Sections 11.2 through 11.5.

Wilson Ditch is another potential pathway of surface water contamination to groundwater. Although surface water concentrations of arsenic are reportedly low in Wilson Ditch (<0.005 to 0.007 mg/L), relatively high concentrations of arsenic have been reported in wells adjacent to Wilson Ditch (EH-128 and EH-132) in the southwestern portion of Lamping Field (Hydrometrics, 2010a). Corrective measures previously implemented for Wilson Ditch included removal of bottom sediments and replacement of the Facility segment of the ditch with an underground HDPE pipeline, which now is rerouted around the Facility (ACI, 2005). However, the segment of the ditch in Lamping Field was not removed, and concentrations in bottom sediments were found to range from 32 to 169 mg/Kg (Hydrometrics, 1990). As part of the Phase II RFI investigation, groundwater level monitoring was conducted in wells in the vicinity of Wilson Ditch, piezometers were installed and monitored, and a synoptic streamflow survey was performed (Hydrometrics, 2010a). The objective of these studies was to better characterize the pathway between Wilson Ditch and groundwater. Surface water and GWSWI results are presented in Section 8; and current conditions are described in Sections 11.2 through 11.5.

According to the CC/RA report (Hydrometrics, 1999a), surface water runoff from the Facility is another potential pathway of arsenic and metals to groundwater. In 1997, a stormwater containment tank system was installed to contain runoff north of the Facility. As described in the RCRA CC/RA, the tank and its secondary containment were designed to contain the 25-year, 24-hour storm. Surface water overflow from the stormwater tank will pond in a designated surface water impoundment area that was designed to retain the 100-year, 24-hour storm event. The unlined surface water impoundment area offers a potential pathway for surface water infiltration to groundwater.

11.1.1.5 Soil to Surface Water Pathway

Erosion and transport of soil as overland runoff to surface water provides a potential contaminant pathway (Hydrometrics, 2005). With the completion of a large stormwater improvements project in 1997, stormwater discharges to surface water are possible only

when the 100-year, 24-hour storm event is exceeded. Even under these conditions, however, there would be no direct outfall to surface water bodies because storm runoff overflow would run into Lamping Field, a large, METG-owned agricultural field.

Erosion of the slag pile, particularly in the area where the slag pile is in contact with Prickly Pear Creek, is a more likely pathway to surface water and Prickly Pear Creek. Although water quality sampling results show very limited evidence of water quality effects from slag, there is visual evidence of slag in Prickly Pear Creek sediments adjacent to the Facility.

11.1.2 Groundwater Contaminant Source Areas

Assessment of potential contaminant sources to groundwater at the Facility has been conducted on numerous occasions for past site investigation and remediation activities. As part of the *Comprehensive RI/FS* activities (Hydrometrics, 1999a), the EPA identified four primary sources of potential contamination at the Facility based on elevated metals concentrations in environmental media. These included smelter emissions, ore storage areas, the slag pile, and process fluids associated with process ponds and process fluid transport circuits (EPA, 1987). More recently, the *Phase I RFI* examined Facility soil as an ongoing source of contaminants to groundwater (ACI, 2005).

Based on the Facility's history, the current configuration of the arsenic and selenium plumes in groundwater, available soils data, and the geochemical controls on selenium and arsenic mobility in groundwater, a preliminary hypothesis regarding current contaminant loading to groundwater at the Facility has been developed for arsenic and selenium (Hydrometrics, 2010a; GSI, 2011). This hypothesis is described below.

11.1.2.1 Arsenic Source Areas

Process Water

The only operating process pond remaining at the site is Lower Lake. As discussed above, arsenic concentrations in Lower Lake have exceeded MCLs since termination of Facility operations (see Section 11.1.1), indicating that it is not an ongoing source of arsenic to groundwater. Figure 11-2 (Hydrometrics, 2010a) combines the May 2009 groundwater arsenic plume, represented by the 0.010 mg/L isocontour and the 10 mg/L isocontour lines, with the calculated 90th percentile soil arsenic concentrations for saturated zone soils. As shown in Figure 11-2, an arsenic plume with concentrations exceeding the MCL of 0.01 mg/L encompasses Lower Lake, a result that is consistent with the hypothesis that Lower Lake is a source.

In addition to infiltrating surface water, submerged sediment in Lower Lake is a potential source of arsenic to groundwater. As part of the Phase II RFI, contaminant levels in Lower Lake sediment were sampled and compared with groundwater protection screening levels. Phase II RFI surface water and sediment results are presented in Sections 8 and 9, respectively; current conditions are described in Sections 11.2 through 11.5.

Saturated Soil

Past sampling of the Facility process water circuit has shown that arsenic concentrations within the process circuit were elevated and variable by location. According to data in Table 11-1, arsenic concentrations were highest in the Speiss Area, followed by the Acid Plant Area shown in Figure 2-3. Because the Speiss Granulation Pit and pond and the Acid Plant Settling Pond are known historical sources of process water leakage to the subsurface, this

implies process water from these areas were historical sources of arsenic to groundwater and soil.

The importance of saturated soils in these former processing areas is indicated by the overlap of the higher concentration arsenic groundwater contour (10 mg/L) with elevated saturated zone arsenic concentrations in the Acid Plant and Acid Plant Sediment Drying Area and the former Speiss Handling Area (Figure 11-2) (Hydrometrics, 2010a). Soil samples collected in the vicinity of the Acid Plant, including both historical samples and samples collected during recent demolition activities, show that saturated zone 90th percentile soil arsenic concentrations exceed 500 mg/Kg throughout much of the area, with one sample from historical well APSD-13 (now abandoned) showing a 90th percentile concentration of 13,211 mg/Kg. In the central portion of the Facility near the former Speiss/Dross Area, saturated zone arsenic concentrations are slightly less elevated, with 90th percentile concentrations ranging from about 150 mg/Kg to 700 mg/Kg. Finally, elevated saturated zone soil arsenic concentrations are shown to persist in a downgradient (northwest) direction along the axis of the arsenic plume, with 90th percentile concentrations of 1,173 mg/Kg arsenic and 627 mg/Kg arsenic observed at locations approximately 400 feet and 800 feet downgradient of the former Speiss Handling Area.

Because the southern extent of the arsenic plume is upgradient of Lower Lake and the Acid Plant, it appears that storage of high arsenic concentration materials in the Tito Park Area continues to load arsenic to groundwater (Hydrometrics, 2010a). As shown in Figure 11-2, soil arsenic concentrations in saturated zone samples from the Tito Park Area contain elevated arsenic levels, with 90th percentile concentrations as high as 2,200 mg/Kg at a site along the northern margin of Upper Lake.

Additional Phase II RFI saturated soil samples were collected to supplement the existing soils database. Included were samples from potential arsenic source areas and a delineation of arsenic concentrations with depth in these areas. Sequential leaching tests were conducted to determine the solubility of arsenic in saturated soils. Phase II RFI soil results are presented in Section 6 and current conditions are described in Sections 11.2 through 11.5.

Unsaturated Soil

Unsaturated zone soil arsenic concentrations are elevated in the main processing area of the Facility. This result is shown in Figure 11-3 as median and 90th percentile arsenic concentrations reported during 2007/2008 demolition activities (Hydrometrics, 2010a). The 90th percentile arsenic concentrations ranged from more than 2,000 mg/Kg in surface soil to more than 100 mg/Kg in soil at a depth of 10 feet bgs. By comparison, the background concentration for arsenic for the Helena Valley soil is 16.5 mg/Kg (MDEQ, 2010a).

Figure 11-3 highlights the importance of depth to groundwater on unsaturated soil as a potential source of arsenic. In the upgradient Tito Park Area (Figure 2-3), groundwater is shallow and surface soil contamination (typically exceeding 1,000 mg/Kg, and some areas in excess of 10,000 mg/Kg) has less distance to travel to groundwater than more downgradient areas of the site. In the Lower Ore Storage Area, groundwater is more than 40 feet bgs. Although arsenic concentrations in the top 10 feet range from 7 to 357 mg/Kg (at SC-3), these concentrations are reduced to background levels (8 to 14 mg/Kg) at a depth of 20 feet bgs. As a result, arsenic loading to groundwater in the Lower Ore Storage Area was hypothesized to be small (GSI, 2011).

Slag

Unsaturated slag also has elevated concentrations of arsenic (100 to 1,000 mg/Kg; Hydrometrics, 2010a) and leachate concentrations that exceed MCLs (0.02 to 0.59 mg/L) (Hydrometrics, 1990). As discussed in Section 11.1.1, for slag to have served as a source to groundwater, it would need to have been leached by surface precipitation at rates exceeding the sorptive capacity of underlying soil. As shown in Figure 11-2, there is a groundwater arsenic plume underlying the slag, but arsenic at this location may originate upgradient of the slag pile. Phase II RFI sampling and analysis included samples from paired groundwater wells DH-74 and DH-75 in the slag pile to evaluate vertical and geochemical gradients in the slag. Additional batch leach tests also were conducted on slag. Phase II RFI soil and leachate test results are presented in Section 6 and current conditions are described in Sections 11.2 through 11.5.

11.1.2.2 Selenium Source Areas

Process Water

The only operating process pond remaining at the Facility is Lower Lake. As discussed above, selenium concentrations in Lower Lake have not exceeded MCLs since termination of Facility operations (see Section 11.1.1), indicating that it is not an important source of selenium to groundwater. This hypothesis is consistent with the selenium groundwater plume map in Figure 11-4 (Hydrometrics, 2010a), which combines the May 2009 groundwater selenium plume, represented by the 0.050 mg/L isocontour and the 1 mg/L isocontour lines, with the calculated 90th percentile soil selenium concentrations for saturated zone soils. As shown in Figure 11-4, the selenium plume (defined by concentrations exceeding the MCL) does not extend upgradient to Lower Lake.

An alternative explanation for the eastern lobe of the selenium plume is that it represents process water originally discharged to Lower Lake before Facility closure in 2001, and is now propagating through the groundwater system with minimal attenuation and loading from site soils or other sources (Hydrometrics, 2010a). The following supporting evidence for this hypothesis was reported:

1. Concentrations at well APSD-7 near the northeast corner of Lower Lake have generally decreased since 2001.
2. The predominant chemical form of selenium in groundwater in this area of the Facility is Se(VI), which behaves relatively conservatively in water (see Section 11.1.3).
3. The current location of the highest selenium concentrations in this area of the Facility coincides with high sulfate (another presumably conservative constituent) (GSI, 2011).

On the eastern portion of the Facility, the selenium plume appears to have migrated about 1,200 feet downgradient of Lower Lake.

As part of the Phase II RFI, an additional monitoring well (DH-76) was completed to further delineate the extent of the eastern selenium plume. Continued sampling of the existing

groundwater monitoring well network was also conducted, to provide well-by-well concentration changes as a function of time. Finally, Phase II RFI sampling and analysis included samples from paired groundwater wells DH-74 and DH-75 in the slag pile to evaluate vertical and geochemical gradients in the slag (additional leaching tests also were conducted on slag). Phase II RFI groundwater results are presented in Section 7 and current conditions are described in Section 7 and Sections 11.2 through 11.5.

Saturated Soil

Similar to arsenic, elevated concentrations of selenium in process water (Table 11-1) likely resulted in historical loading to soil. However, selenium may be less easily attenuated compared with arsenic in the subsurface (Langmuir et al., 2005), and loading of selenium onto soils through process water releases would have been much less significant (except in the highly reduced central portion of the arsenic plume where redox conditions indicate potentially low solubility and possible retention as elemental selenium Se(0) [GSI, 2011]).

Saturated zone (and unsaturated zone) soil concentrations for selenium are very limited (Figure 11-4). These data indicate saturated zone selenium concentrations are elevated over background concentrations (0.07 mg/Kg for Helena Valley soil). During the Phase II RFI, saturated soil samples were collected to supplement the existing soils database, including samples from additional selenium source areas and samples to define selenium concentrations with depth in these areas. Sequential batch leach tests were conducted to determine the solubility of selenium in these soils. Phase II RFI soil and leach test results are presented in Section 6; current conditions are described in Section 6 and Sections 11.2 through 11.5.

Unsaturated Soil

On the western side of the selenium plume, the plume centroid (area of highest concentration) appears to have migrated some distance downgradient with potentially conservative tracers of process waters (chloride and sulfate), suggesting that the most significant source of selenium to groundwater (process water) may have been removed (Hydrometrics, 2010a). However, the western selenium plume extends upgradient and the upper end of the plume is approximately coincident with the arsenic plume, indicating some ongoing loading of selenium to groundwater. Elevated concentrations of selenium in unsaturated zone soils (collected during the Monier Flue demolition) have been observed in this area (Figure 11-3).

Slag

Primary objectives of the Phase II RFI were to collect additional selenium data to (1) determine whether site soils and slag are acting as a source of selenium loading to groundwater, and (2) better understand the mechanisms governing selenium distribution in site groundwater. Phase II RFI soil and leach test results are presented in Section 6; current conditions are described in Section 6 and Sections 11.2 through 11.5.

11.1.3 Contaminant Geochemistry

A detailed description of the environmental chemistry of arsenic, metals (cadmium, copper, iron, lead, manganese, and zinc), and petroleum hydrocarbons is included in the *Comprehensive RI/FS* (Hydrometrics, 1990) and in of the *CC/RA* (Hydrometrics, 1999a). A discussion of selenium geochemistry was also included in the *Phase II RFI Work Plan*

(Hydrometrics, 2010a). These reports concluded that the fate of arsenic and selenium is determined by their chemical properties and geochemical changes (e.g., pH, redox potential, ionic strength, etc.) that take place in the environment. The discussion below summarizes the environmental chemistry of arsenic and selenium, which were determined to be the contaminants of greatest concern in groundwater. The objective is to provide context for an evaluation of the current understanding of the fate and transport of arsenic and selenium in groundwater presented in Sections 11.2 through 11.5 of this report.

11.1.3.1 Arsenic

The aqueous speciation of arsenic is dominated by the oxyanions arsenate ($\text{H}_n\text{AsO}_4^{n-3}$) under oxidizing conditions, and arsenite ($\text{H}_n\text{AsO}_3^{n-3}$) under reducing conditions, although thioarsenic (sulfur-containing) species may occur under sulfate-reducing conditions with depleted iron concentrations (EPA, 2007b; Vlassopoulos et al., 2010). Arsenate species include arsenic in the +5 oxidation state (As(V)), and arsenite species include arsenic in the +3 oxidation state (As(III)). The level of protonation of arsenate and arsenite is a function of pH.

As shown in Figure 11-5 (GSI, 2011), arsenic exists as a mixture of both As(III) and As(V) aqueous species in onsite and offsite groundwater. In addition, arsenic is not predicted to form stable secondary mineral phases (shown as gray shaded fields) in most Facility groundwater. This result suggests that arsenic oxide minerals (related to air emission sludges and dusts) and sulfide solid-phases (present in slag and ore concentrate) are unstable and will dissolve over time.

Arsenic transport in groundwater typically is controlled via adsorption/desorption and coprecipitation mechanisms. In practice, adsorption and coprecipitation mechanisms may be difficult to distinguish via typical analytical data collected as part of environmental investigations (Langmuir et al., 2005). As noted in EPA (2007a), precipitation of pure phase arsenic minerals is improbable in most groundwater systems outside of source areas; however, coprecipitation with oxides and/or sulfides of metals, such as iron, is considered to be a likely sink for arsenic in groundwater in redox transition zones (i.e., where aquifer conditions change from reducing to oxidizing, or vice-versa). Both As(III) and As(V) have been reported to coprecipitate with hydrous iron and manganese oxides. As with other forms of arsenic, the long-term stability of arsenic coprecipitated minerals will depend on potential changes in redox, pH, and ionic composition of groundwater as contaminant source areas are removed or otherwise mitigated, and groundwater geochemical conditions are returned to “natural” steady-state condition.

Adsorption of both arsenate and arsenite is strongly pH dependent, and also is influenced by the concentration of other anions in solution that may compete for adsorption sites on aquifer materials. Langmuir et al. (2005) noted that arsenate adsorbed to hydrous ferric oxide is strongly bound at pH values below 8, and desorbed between pH 9 and 11. The iron oxides and sulfides noted above that serve as potential coprecipitating minerals with arsenic are also apparently predominant as adsorptive materials in oxidizing and reducing conditions, respectively (EPA, 2007a). Adsorbents such as clays or organic matter may be less important adsorptive controls for anions such as arsenate and arsenite, because of their negative surface charge under the range of natural pHs.

The *Phase I RFI* (ACI, 2005) provided several lines of evidence that suggest adsorption and/or coprecipitation of arsenic with iron and manganese oxides is occurring in the subsurface, and therefore is likely to be the principal mechanism for attenuation of arsenic in groundwater at the Facility. The lines of evidence presented include:

1. Abundance of iron and manganese oxides in Upper Aquifer sediments
2. Enrichment of arsenic in iron and manganese mineral phases (determined through sequential extraction analyses of saturated zone aquifer soils)
3. Trends in dissolved iron and manganese concentrations along the groundwater flow path that suggest removal via oxidation/precipitation, providing the conditions for coprecipitation of arsenic with iron and manganese minerals, and the formation of additional adsorptive capacity (metal oxide/hydroxide surfaces) within the aquifer

11.1.3.2 Selenium

Similar to arsenic, selenium may exist in multiple oxidation states in the aqueous phase, including selenide ($\text{Se}(-\text{II})$), elemental selenium ($\text{Se}(0)$), selenite ($\text{Se}(\text{IV})$), and selenate ($\text{Se}(\text{VI})$) (EPA, 2007b). The $\text{Se}(\text{IV})$ and $\text{Se}(\text{VI})$ states commonly occur as the oxyanions SeO_3^{2-} (selenite) and SeO_4^{2-} (selenate) (Figure 11-6) (GSI, 2011). Selenium speciation and, consequently, selenium mobility in groundwater is highly dependent on pH and redox conditions, as illustrated in Figure 11-6.

In contrast to arsenic, attenuation of selenium in soils is positively correlated with the formation of reducing environmental conditions (EPA, 2007b). Selenite behaves like phosphate and is strongly adsorbed by hydrous ferrous oxides (Plant et al., 2007) (although sorption decreases significantly above pH values of about 8.5). According to EPA (2007b), selenate (the more oxidized form) is analogous to sulfate, with little adsorption and high mobility.

Elemental selenium ($\text{Se}(0)$) or highly insoluble metal selenides also may precipitate under reducing conditions, resulting in very low dissolved selenium concentrations in groundwater. Reoxidation of elemental selenium to more mobile selenite or selenate oxyanions is relatively slow, suggesting that $\text{Se}(0)$ phases formed in soil may be important long-term sinks for selenium (EPA, 2007b).

Onsite and offsite groundwater are plotted on the Eh-pH stability diagram in Figure 11-6 using reported concentrations of $\text{Se}(\text{IV})/\text{Se}(\text{VI})$ to calculate the oxidation-reduction potentials of groundwater samples. As shown in Figure 11-6, $\text{Se}(\text{VI})$ is the predominant species in all locations except the APSD Area (where waste material likely included $\text{Se}(\text{IV})$ as $\text{Se}^{\text{IV}}\text{O}_2$). It is important to note that Figure 11-6 does not show groundwater samples with reported non-detect concentrations. Therefore, because of the low solubility of $\text{Se}(0)$, this diagram cannot be used to discern the occurrence of elemental selenium. Eh estimates based on oxidation reduction potential (ORP) in groundwater wells in the central portion of the Facility are shown in Figure 11-6 to be within the stability field of $\text{Se}(0)$ (GSI, 2011).

11.1.3.3 Summary

Previous investigations reported that arsenic and selenium are redox sensitive elements that may occur in several oxidation states depending primarily on pH and redox conditions in groundwater and aquifer materials. They commonly exist as oxyanions in solution, and are adsorbed to metals oxides and/or sulfides to varying degrees, with attenuation behavior depending on the pH and redox status of groundwater. One of the chief differences in the geochemical behavior of selenium compared with arsenic is the relative immobility of selenium under reducing conditions (Plant et al., 2007). Elemental selenium is highly insoluble, and selenite (Se(IV)) adsorbs more strongly to soil than selenate (Se(VI)). Sections 11.2 through 11.5 build upon this information to evaluate current contaminants sources and groundwater plume stability.

11.1.4 Groundwater Transport of Arsenic and Selenium

As discussed above, arsenic and selenium can occur in multiple oxidation states and chemical species, and their fate and transport in groundwater systems is closely linked to geochemical conditions within the aquifer. The following discussion reviews site geochemistry and its effect on arsenic and selenium transport, based on the results and conclusions of previous investigations.

11.1.4.1 Extent of Arsenic and Selenium Plumes

Arsenic and selenium plume maps were developed to guide the Phase II RFI sampling and analysis program. These maps are shown in Figures 11-7 and 11-8, respectively (Hydrometrics, 2010a). The concentration isocontours in Figures 11-7 and 11-8 were based on groundwater data collected at the site in May/June 2009. Figures 11-7 and 11-8 show that the general orientation of the arsenic and selenium plumes is the same, with both extending from the southeastern portion of the Facility toward the northwest. Although both plumes are relatively narrow laterally compared with the plume length, the lower concentration arsenic plume (represented by the 0.010 and 0.050 mg/L contour) is broader and extends farther to the east than the selenium plume.

As flowing groundwater is affected by a variety of historical source areas beneath the Facility, arsenic concentrations eventually reach a maximum of more than 100 mg/L in the central portion of the Facility near the former Speiss Handling area (Figure 11-7).

Downgradient of the Facility, arsenic concentrations decrease rapidly, by approximately 3 orders of magnitude (1,000-fold) within about 1,200 feet. As of 2009, the extent of the 0.010 mg/L plume was limited to the area south of Clinton Street on the northern edge of the City of East Helena, and the area east of 4th Avenue (Wylie Drive) on the western edge of the City.

Groundwater selenium concentrations reach a maximum concentration of about 1 to 3 mg/L in the vicinity of the thaw house and CSHB on the western side of the Facility (Figure 11-8). In contrast to arsenic, selenium persists farther to the north. The northern extent of the selenium plume (as represented by the 0.050 mg/L contour) is not fully defined in this 2009 snapshot. One of the objectives of the Phase II RFI was to delineate the northern extent of the 0.05 mg/L selenium plume. Phase II RFI groundwater results are presented in Section 7; current conditions are described in Section 7 and Sections 11.2 through 11.5.

11.1.4.2 Plume Geochemistry

The shallow groundwater system on the upgradient (southeast) end of the Facility is reportedly dominated by influx of fresh, relatively oxygenated water from Upper Lake (Hydrometrics, 2010a). Upper Lake was created by a diversion of Prickly Pear Creek surface water upstream of the Facility, and thus water quality in Upper Lake is similar to Prickly Pear Creek water quality, with a near-neutral to slightly alkaline pH, relatively low conductivity, and low but occasionally detectable concentrations of arsenic (<0.003 to 0.010 mg/L) (note: selenium concentrations in Upper Lake/Prickly Pear Creek water are not well-characterized). By contrast, pH and redox conditions underlying the site are highly variable as a result of historical releases of process water and the storage and disposal of ore, soils, sediment, and slag.

The relationship between groundwater redox status and the geometry of the arsenic and selenium plumes is shown in Figure 11-9 (Hydrometrics, 2010a). Groundwater redox potentials based on the ratios of As(III) and As(V) at six representative wells in November 2008 were calculated and plotted on a map showing the 1.0 mg/L arsenic contour and the 0.050 mg/L selenium contour. The main high concentration groundwater arsenic plume occurs in a highly reducing environment (approximately -250 mV, based on data from well DH-33), while dissolved selenium concentrations are low in this low Eh environment (note: reducing conditions could be the result of elevated concentrations of reduced redox species As(III)/Fe(II) and/or the result of petroleum hydrocarbon degradation in the central portion of the Facility). Results show arsenic concentrations are highest (i.e., arsenic is most mobile) under relatively reducing conditions (where iron and manganese oxide minerals available for arsenic adsorption are unstable). By contrast, selenium concentrations are lowest under these conditions.

With increasing distance downgradient and laterally from the high arsenic concentration plume, arsenic speciation ratios indicate increasingly oxidizing conditions and decreasing arsenic concentrations. These lateral (and downgradient) areas are also where the higher concentrations of selenium in groundwater are observed. Selenium speciation groundwater data show that most dissolved selenium in groundwater consists of the oxidized (selenate or Se(VI) form). This is consistent with the general observation that oxidized forms of selenium are relatively mobile in groundwater, while reduced forms are largely removed from solution through precipitation or adsorption reactions.

In summary, the speciation data and arsenic/selenium plume configurations suggest the following CSM for arsenic and selenium transport in groundwater (ACI, 2005; GSI, 2011; Hydrometrics 1999a and 2010a):

1. Upgradient of the Facility, oxidizing water from Prickly Pear Creek via Upper Lake contributes appreciable flux to the groundwater system.
2. Historical and/or ongoing source areas within the Facility (discussed in Section 11.1.2) elevate arsenic and selenium concentrations in groundwater underneath the southeast and central portions of the Facility.
3. Reducing conditions (evidenced by low Eh and high levels of reduced redox-sensitive species) promote removal of selenium from groundwater in the central portion of the plume and high mobility of arsenic.

4. As groundwater moves downgradient, influx of oxidizing water from Prickly Pear Creek, dilution with unimpacted groundwater, and interaction with aquifer materials moderate the Eh/pH conditions of groundwater, and oxidizing conditions are re-established.
5. Arsenic adsorbs and/or co-precipitates with iron oxides that are stable in the downgradient plume. Selenium mobility is enhanced under oxidizing conditions because of the high mobility of Se(VI).
6. Although pH may affect adsorption under alkaline conditions, which predominantly occur in the Speiss/Dross Area. As a result, pH is likely a secondary factor contributing to arsenic and selenium mobility.

The Phase II RFI included additional characterization of organics, which, as mentioned above, potentially affects Facility redox conditions. Batch adsorption tests also were performed on soil from onsite and offsite areas to characterize the sorption capacity of study area soils, and, therefore, better predict the long-term fate of arsenic and selenium. Phase II RFI soil and leach test results are presented in Section 6; current conditions are described in Section 6 and Sections 11.2 through 11.5.

11.1.4.3 Plume Stability

Figure 11-10 (Hydrometrics, 2010a) compares the 10 mg/L and 0.010 mg/L groundwater isocontours from November 2002 (adapted from the plume maps presented in the *Phase I RFI*) and from May 2009. As shown in Figure 11-10, the downgradient margins of the arsenic plume (represented by the 0.010 mg/L contour) exhibit very little change during the period between 2002 and 2009. The higher concentration (10 mg/L) plume closer to the historical source areas, appears to have shown a slight contraction, or at least no signs of expansion. The relative stability of the downgradient arsenic plume and the slight contraction of the higher concentration plume nearer the historical source areas is consistent with the removal or other mitigation of identified sources that has occurred at the Facility, termination of Facility operations, and with ongoing arsenic attenuation at the plume front through adsorption and/or coprecipitation mechanisms.

Temporal trends in arsenic concentration for individual wells in historical source areas, and at the northern extent of the “higher concentration” (10 mg/L) arsenic plume are shown in Figure 11-11 (Hydrometrics, 2010a). Wells near the former Acid Plant and former Speiss/Dross Area show relatively consistent decreases in arsenic concentration over time. Wells downgradient of Lower Lake also show decreasing groundwater arsenic concentrations in the late 1980s and early 1990s, with the rate of decrease slowing significantly after about 1995. At downgradient offsite well EH-60, arsenic concentrations increased from about 1987 through 2001, and have decreased consistently in subsequent years. Finally, well EH-100, located one city block east of EH-60, had very low arsenic concentrations when initially sampled in 1986, but when the well was added to the routine monitoring list again in 2001, arsenic concentrations had increased significantly. Concentrations at this well were found to be similar to, or slightly higher than, concentrations at EH-60, although arsenic concentrations at EH-100 show significantly more seasonal variability than concentrations at EH-60.

There is little time-concentration data for selenium because selenium only recently was identified as a COC at the Facility and there is little historical groundwater selenium data to

compare with current concentrations. A goal of the Phase II RFI was to better define the spatial (horizontal and vertical) extent of selenium in groundwater and to provide continued plume monitoring. Phase II RFI groundwater results are presented in Section 7; current conditions are described in Section 7 and Sections 11.2 through 11.5.

11.2 Phase II RFI

Overall objectives of the Phase II RFI included:

- Defining current site conditions in terms of the magnitude and extent of contaminant-impacted soils on the Facility, accounting for past and ongoing site remediation activities.
- Identifying and delineating source area(s) for the arsenic and selenium groundwater plumes.
- Evaluating the fate and transport of arsenic and selenium in the subsurface, and the current status and predicted future behavior of the groundwater plumes.
- Providing information and data required for completion of the human health and ecological risk assessment portions of the Phase II RFI, and an RCRA CMS.

Results of the Phase II RFI are presented in Sections 6 through 10. The following discussion summarizes and interprets data collected to address contaminant fate and transport.

Section 11.2.1 reports the COCs identified from groundwater chemistry results. Section 11.2.2 reviews data aimed at updating the site conceptual model for contaminant sources. Section 11.2.3 evaluates data concerning the nature and extent of the arsenic and selenium groundwater plumes. Finally, Section 11.2.4 evaluates data collected to better understand fate and transport, and whether governing geochemical processes have changed since Facility closure.

11.2.1 Contaminants of Concern

The groundwater quality data set evaluated from the monitoring network is shown in Figure 7-1 (a description of sampling methodology and analytical results are in Sections 4 and 7). It was found that numerous constituents continue to exceed project SLVs (Table 7-7). These exceedances include aluminum, antimony, arsenic, cadmium, iron, lead, manganese, mercury, selenium, thallium, vanadium, and zinc (Tables 7-7 and 11-2). The highest exceedance rate is exhibited by arsenic, where approximately 43 percent of samples collected from 2008-2010 exceed the 0.010 mg/L drinking water standard. Arsenic is followed by manganese (31 percent), selenium (23 percent), iron (16 percent), antimony (15 percent), cadmium (9 percent), thallium (8 percent), zinc (3 percent), and lead (1 percent). Groundwater within, and in some areas downgradient, of the Facility also exceeds federal SMCLs for sulfate, chloride, and TDS. SMCLs are non-mandatory guidelines established by EPA for aesthetic considerations, and these exceedances do not indicate a risk to human health.

As shown in Table 11-2, offsite exceedances of groundwater SLVs are limited to antimony, arsenic, manganese, and selenium. However, because offsite antimony and manganese exceedances are restricted to a limited number of wells (Figures 7-2 [a-b] and 7-9 [a-b], respectively), and these occur in areas encompassed by the arsenic and selenium plumes

(Figures 7-3 [a-d] and 7-10 [a-d], respectively), arsenic and selenium remain the primary Facility-related COCs in groundwater¹⁷.

11.2.2 Ongoing Contaminant Sources

This section evaluates the following potential current sources of contamination at the site: (1) Lower Lake (including HDS effluent discharges and lake sediment), (2) saturated soil in direct contact with groundwater, (3) unsaturated soil, (4) slag, and (5) Prickly Pear Creek and Wilson Ditch. These sources were identified during previous site investigations (described in Section 11.1) and from the results of the Phase II RFI presented in Sections 6 through 10.

11.2.2.1 Arsenic Source Areas

Process Water

As discussed in Section 11.1.2, previous surface water sampling of Lower Lake indicates arsenic concentrations exceed groundwater MCLs. This result implies Lower Lake is a potential source of arsenic to groundwater. One objective of the Phase II RFI at Lower Lake was to evaluate the potential loading of arsenic and selenium to groundwater. Data included surface water, sediment, and stormwater quality characterization. In addition, a stable isotope investigation of Lower Lake and downgradient monitoring wells was conducted as part of a separate study. It provides insight on the relative contribution of Lower Lake to groundwater flow.

Figure 11-12 compares arsenic concentrations in Lower Lake with downgradient monitoring well DH-4 (note: DH-5 is also immediately downgradient, but may be influenced by water leakage from the City of East Helena potable water supply line; ACI, 2005). Figure 11-12 shows that before full-time operation of the HDS water treatment plant in 1994/1995, arsenic concentrations in Lower Lake were higher than groundwater, but since that time, concentrations have been less. The trends shown in Figure 11-12 are consistent with Lower Lake originally serving as a source of arsenic to both groundwater and underlying soils/sediment, but with other sources currently supplying a greater proportion of the dissolved arsenic load to downgradient monitoring wells. Current treated stormwater discharges from the HDS treatment plant do not exceed the SLV for protection of groundwater for arsenic (see Section 10).

Surface sediment sampling locations for the Phase II RFI are shown in Figure 9-1, and tabulated results for selected analytes are reported in Section 9 and summarized in Table 11-3. Results for Lower Lake samples LL-24 through LL-21 confirm the presence of elevated concentrations of arsenic in surface sediment (94 to 901 mg/Kg), and indicate that contaminated sediment remains in Lower Lake despite process sludge dredging in the mid-1990s. Although this (and underlying) sediment is a potential source to groundwater,

¹⁷ Remedial alternatives developed or implemented to address arsenic and/or selenium presumably will address antimony and manganese. For example, elevated groundwater manganese concentrations are at least partly related to reducing conditions generated by high levels of As(III) in the arsenic groundwater plume (ACI, 2005). Also, the geochemistry of antimony is similar to arsenic (Wilson et al., 2010), and corrective measures addressing arsenic necessarily would reduce antimony concentrations in groundwater. As part of the corrective measures study, the effectiveness of alternatives in reducing groundwater concentrations of antimony and manganese would need to be evaluated.

deeper core samples would be required to understand the depth distribution of arsenic underlying Lower Lake.

The relative contribution of Lower Lake to groundwater flow (and thus potential for sediment/soil to contribute to the groundwater plume) is evidenced by the similarity between the isotopic signature of Lower Lake and downgradient groundwater monitoring wells. As discussed in GSI (2011), Lower Lake has a unique oxygen isotope ratio signature of a pit lake (characterized by enrichment in $\delta^{18}\text{O}$ resulting from evaporation that preferentially depletes $\delta^{16}\text{O}$; Gammons et al., 2006). As shown in Figure 11-13, a large portion of Facility data has an evaporated surface water isotopic signature.

Saturated Soil

As discussed in Section 11.1.2, arsenic historically loaded onto site soils will function as an ongoing source to groundwater. Predominant areas of high arsenic concentrations in saturated soils previously were found to include the Acid Plant and Acid Plant Sediment Drying Area, the former Speiss/Dross Handling Area, and Tito Park (Figure 2-3). As part of the Phase II RFI, saturated soil samples were collected to provide additional information on the distribution and solubility of metals in subsurface soils, and to examine the relationship between saturated soil concentrations and the arsenic and selenium groundwater plumes.

Figure 11-14 shows the locations of soil samples collected during the Phase II RFI. Locations were selected on the basis of the current groundwater plume configurations for arsenic and selenium, the distribution of available soils data for arsenic and selenium, and the need for additional data to test the assumptions that site soils may be acting as an ongoing source of arsenic to groundwater. Subsamples selected for adsorption/leach testing were based on the observed total selenium and arsenic results, sample locations relative to the current arsenic and selenium groundwater plume configurations observed at the Facility (Figure 11-15), and objectives outlined above.

The 90th percentile saturated soil arsenic concentrations are shown in Figure 11-16. This distribution is similar to previous investigations (Figure 11-2), with the highest concentrations occurring in the main processing areas of the Facility (the Acid Plant and Speiss/Dross Areas) and lowest in the most downgradient locations. Soil borings in Tito Park highlight the variability in soil arsenic concentrations in this area of the site (30 mg/Kg to more than 1,000 mg/Kg).

The depth-distribution of arsenic in saturated soils is reported in Table 11-4. The highest arsenic concentrations in saturated soils typically occur near the water table. Also, the saturated thickness where arsenic concentrations exceed the background value (16.5 mg/Kg), range from <10 to 20 feet bgs. Finally, arsenic contamination does not appear to penetrate the underlying Aquitard and Tertiary units (concentrations for these intervals are within background levels).

SPLP and sequential batch leach tests also were conducted on selected site soil samples to determine their long-term leaching behavior (Appendix 11-A). Results from these tests are reported in Tables 6-12 and 6-13, respectively. Sequential batch leach tests were performed on saturated soil samples collected from borings: RFI2SB-3, RFI2SB-8, RFI2SB-16, RFI2SB-18, RFI2SB-21, and RFI2SB-22. As shown in Table 6-13 and Figure 11-17, arsenic concentrations are generally highest during the initial extractions, but plateau to levels that are between 12

and 61 percent of the initial concentrations after several sequential steps (the exception is RFI2SB-8, which exhibits a relatively uniform leaching rate). Results indicate that all of the tested saturated soil samples are capable of generating and maintaining arsenic concentrations above MCL values throughout sequential leaching (although extrapolation of the reported values to in-situ conditions is not necessarily straightforward). There is also a weak, but positive, correlation between arsenic concentrations in leachate and soils, with the highest levels found in RFI2SB-18 (1,260 to 1,710 mg/Kg and 0.43 mg/L, respectively).

Finally, sequential extraction tests were conducted on several saturated soil samples to understand the primary arsenic-bearing phases in the soils. Results are presented in Table 6-14 and Figure 11-18. Arsenic is shown to be associated with several chemical forms in soil, including adsorbed chemical forms (9 to 38 percent of the arsenic is removed in Fraction I that uses phosphate to replace arsenic on available soil adsorption sites). Results also identify the presence of arsenic adsorbed and/or co-precipitated with iron oxides (Fractions 4 and 5), and the presence of little residual arsenic (Fraction 7) in saturated soils.

It is important to understand that the exact operationally defined fraction shown in Table 6-14 and Figure 11-18 is merely an estimate because the different extraction steps (represented by the different fractions in Table 6-14) may not selectively liberate only the targeted mineral phase(s). There are also different extraction procedures that have been developed to try to identify arsenic speciation in soils (Smedley and Kinniburgh, 2002), and that the method selected for this study was developed specifically for selenium (Piatak et al., 2006). A different approach, using $(\text{NH}_4)_2\text{SO}_4$ as the first extractant (Wenzel et al., 2001), would remove the non-specifically bound arsenic that is most likely liberated in the SPLP and sequential batch tests. Also, measuring dissolved iron, manganese, and aluminum during the sequential extraction experiments would provide an estimate of the amount of adsorbing phases present in the soil. Finally, electron microprobe analysis (EMPA) or other methods, such as X-ray absorption spectroscopy (XAS), would improve understanding of arsenic (and selenium) sequestration mechanisms in soil (Cances et al., 2005).

Unsaturated Soil

The depth distribution of arsenic concentrations in soil borings collected during Phase II RFI is shown in Table 11-4. The current distribution of arsenic contamination is presented and discussed in Section 6 for numerous depth intervals in Figures 6-5a through 6-5f. In Tito Park, concentrations are higher than the background value over the entire unsaturated depth, although the distribution of arsenic with depth is non-systematic between samples (a result that might be expected for a storage/disposal area with a varied history of disposal activities). Arsenic concentrations in boring RFI2SB-22 decrease with depth, concentrations in boring RFI2SB-3 increase with depth, and the highest concentrations for boring RFI2SB-2 occur between 2.5 and 5 feet bgs). The high soil arsenic concentrations occur near (and below) the water table, and indicate that Tito Park is likely a source of arsenic to groundwater.

Overall, the highest unsaturated soil arsenic concentrations are in the Acid Plant Area, but areas with unsaturated soil arsenic concentrations greater than 500 mg/Kg also occur in Tito Park (as discussed above), Monier Flue, the Central Plant, Zinc Plant, and Rail Corridor/Thaw House (Figure 2-3). In the most downgradient onsite locations (borings RFI2SB-9, RFI2SB-10, and RFI2SB-11), soil arsenic concentrations recover to within background levels (<16.5 mg/Kg) before reaching the water table (indicating unsaturated

soils may not be a source to groundwater in areas where the water table is relatively deep). Results in Table 11-4 also show that in some cases (borings RFI2SB-4, RFI2SB-5, DH-72, DH-73, RFI2SB-13, and RFI2SB-17) arsenic concentrations in the soil profile immediately below the water table are higher than those above. These occurrences may represent arsenic accumulation from lateral transport (and sequestration) along the groundwater plume flowpath.

SPLP and sequential leaching test results on unsaturated soils are reported in Tables 6-12 and 6-13, respectively. As shown in Table 6-12, there is a high degree of variability in the SPLP leachate concentrations in surface soils (leachate arsenic concentrations from 5 of 16 soil samples [31percent] are below the MCL of 0.01 mg/L, while 19 percent of soil samples are greater than 0.1 mg/L). However, unlike saturated soils, there is not a clear correlation between soil and leachate arsenic concentrations. For example, the soil arsenic concentration in Tito Park sample RFI2SB-6 is 1,460 mg/Kg, but the SPLP leachate is only 0.002 mg/L (note: an explanation for the low solubility of arsenic in RFI2SB-6 is indicated by its sequential extraction results – a high relative abundance of amorphous and crystalline iron oxides (52 percent) and a low relative abundance of exchangeable arsenic (2 percent); Table 6-14). Another difference between unsaturated and saturated soil samples is that the final leachate arsenic concentrations in the sequential batch leach tests are generally lower than saturated soils (0.063, 0.01, and 0.11 mg/L, respectively, for RFI2SB-1, RFI2SB-6, and RFI2SB-16) (Table 6-13).

In summary, SPLP and sequential batch leach tests suggest that surface soils do not leach arsenic at concentrations observed in groundwater near historical sources (e.g., the Speiss pond); however, arsenic in some unsaturated soils is in a form that is fairly leachable and capable of generating solution concentrations that may exceed groundwater standards. The vertical distribution of arsenic in the soil profiles shows that leachable arsenic is present near the water table in much of the site. The exception is in the most downgradient areas, where there remains unused sorptive capacity separating arsenic in shallow soils (<5 feet) and the water table.

Slag

Concentrations of arsenic in three Phase II borings advanced through the slag for installation of monitoring wells DH-74, DH-75, and DH-76 are shown in Table 11-5. Slag concentrations exhibit considerable vertical variability, with concentrations in DH-74 and DH-75 at depths less than 70 feet ranging from 100 to 1,210 mg/Kg, but concentrations at greater depths, ranging from 25 to 142 mg/Kg. In DH-76, the highest concentrations occur at depths between 45 and 85 feet (701 to 3,060 mg/Kg). Table 11-5 also shows that saturated soil samples collected beneath the slag are within the background range (or only slightly elevated), which may indicate some accumulation from either vertical or lateral transport.

Slag SPLP leachate concentrations and sequential extraction results are presented in Tables 6-12 and 6-14, respectively. As reported in Table 6-12, SPLP leachate concentrations (0.009 to 0.130 mg/L) are similar to the range of values reported in Hydrometrics (1990) (0.02 to 0.59 mg/L). These concentrations exceed the MCL for arsenic (0.01 mg/L) in three of four samples. The sequential extraction test results (Table 6-14) show that only about 1 percent of the arsenic in DH-76 is in Fraction 1 (exchangeable), whereas approximately 70 to 75 percent occurs in iron oxides, sulfides/selenides, and residual forms. The occurrence of

arsenic (and selenium) in sulfides/selenides in the slag may result from residual ore minerals that were not fully melted and/or reacted in the smelting process.

In summary, Phase II RFI data suggest that slag has the potential to leach arsenic at concentrations that exceed MCLs, but that slag is heterogeneous and leachate concentrations are variable. Although arsenic concentrations in underlying soil (above the water table) are similarly elevated relative to the background concentration in two of three borings, it is unclear if these soils have been influenced by infiltration from the slag and/or represent native material and/or have been influenced by a fluctuating water table.

Other Sources

Wilson Ditch and Prickly Pear Creek are both potential sources of arsenic to groundwater; however, because surface water concentrations of arsenic are low in each (Figure 8-3), the primary mechanism for groundwater to be impacted is the leaching of arsenic adsorbed to underlying sediment by infiltrating surface water. Table 11-3 shows that because surface sediment concentrations in Wilson Ditch and Prickly Pear Creek are elevated relative to background soils, sediment is at least a potential arsenic source. One location where sediment leaching may have influenced groundwater is in an area in Lamping Field adjacent to Wilson Ditch, where elevated concentrations of arsenic occur in groundwater (Figure 11-2c). Additional sampling and analysis would be required to assess the importance of this potential source.

11.2.2.2 Selenium Source Areas

Process Water

As discussed in Section 11.1.2, previously collected soil and groundwater selenium data suggest that the current groundwater selenium plume may be a transient plume, resulting from historical process water-related sources (see Table 11-1). As part of the Phase II RFI, additional monitoring of Lower Lake and sediment was conducted to understand if Lower Lake is an ongoing current source of selenium to groundwater.

Figure 11-19 compares the limited data on selenium concentrations in Lower Lake with downgradient monitoring well DH-4. Figure 11-19 shows that for the time periods represented (1984-1985 and 2007-2010), selenium concentrations in Lower Lake have always been higher than in DH-4. Because these concentrations are less than the MCL of 0.05 mg/L, Lower Lake surface water does not appear to be a significant source of selenium to groundwater. However, current treated stormwater discharges from the HDS treatment plant generally exceed the SLV for protection of groundwater for selenium (see Section 10).

Surface sediment sampling locations for the Phase II RFI are shown in Figure 9-1, and tabulated results for selected analytes reported in shown in Table 11-3. Results for Lower Lake samples LL-24 through LL-25 confirm the presence of elevated concentrations of selenium in surface sediment (3.3 to 24.9 mg/Kg) relative to background levels (0.07 mg/Kg), indicating historical sediment loading, and the potential for ongoing releases to groundwater. However, because the upgradient extent of the 0.05 mg/L selenium plume now originates downgradient of Lower Lake (Figure 11-8), sediment loading to groundwater also is not likely the source.

The primary impacts associated with Lower Lake likely occurred during historical process water discharges. Evidence that Lower Lake was a historical source includes the relatively

high concentrations measured in 1998 as part of the Facility water release investigation (up to 43 mg/L). That investigation also reported a selenium concentration of 0.47 mg/L in water from the main plant circuit (which at the time discharged to Lower Lake; Table 11-1). It is also important to note that selenium concentrations in the existing monitoring wells in 1984 were below the MCL (Figures 11-20 and 11-21), which suggests that selenium was largely introduced during late Facility operations (note: one potentially confounding issue with this interpretation is the reliability of historical selenium concentration data). Given that current maximum selenium and sulfate concentrations occur at the same locations (GSI, 2011), and the high levels of sulfate introduced in the late 1990s (Figure 11-22), the eastern lobe of the selenium plume may of similar age and origin as the sulfate.

Saturated Soil

Subsurface soil sampling was intended, in part, to determine whether the selenium plume is migrating downgradient with minimal continued loading, or if elevated selenium concentrations exist in site soils, and if so, act as a continuing source of selenium loading to groundwater.

The 90th percentile saturated soil selenium concentrations are shown in Figure 11-23. The distribution of selenium in soils is similar to arsenic in that the highest concentrations occur in the main processing areas of the Facility. Relatively high (>20 mg/Kg) concentrations also occur in soil samples collected from borings for monitoring wells DH-68, DH-69, and DH-71. The depth concentration profiles for many of these samples are shown in Table 11-6. It is reported that concentrations are below the detection limit of 5 mg/Kg in saturated soils in all but three locations (RFI2SB-3 in Tito Park [13 mg/Kg], RFI2SB-18 near the former Acid Plant [76 to 94 mg/Kg], and RFI2SB-17 in the Speiss/Dross Area [17 mg/Kg]).

Results of the sequential batch leach tests on saturated soil samples from borings RFI2SB-3 and RFI2SB-18 are included in Table 6-13 and Figure 11-17. As shown in Table 6-13, each analyzed leachate from the Tito Park Area (RFI2SB-3) is below the MCL for selenium, a result consistent with the lack of an identifiable plume currently in this area of the Facility. By contrast, leachate concentrations from the former Acid Plant soil (RFI2SB-18) indicate concentrations are above the selenium MCL in every sequential leachate.

Results of sequential extraction tests (Table 6-14 and Figure 11-18) indicate selenium in soil sample RFI2SB-3 is associated with the following operationally defined phases: exchangeable (13percent); organics (11 percent); crystalline iron oxides (19 percent); sulfides/selenides (55 percent); and residual (2 percent). Of these, the more soluble fractions would be expected to contribute most selenium to the observed leachate results in Table 6-13. In contrast to RFI2DB-3, selenium in downgradient sample RFI2SB-20 has a higher fraction of selenium in the exchangeable (40 percent) and iron oxide (23 percent) fractions. These results are consistent with downgradient transport and at least partial sequestration by iron oxides (note: EMPA or other methods, such as XAS, would be required to identify the presence of elemental selenium).

In summary, selenium distribution maps and leaching results indicate that there are only a few locations with elevated levels of selenium in saturated soils relative to the background concentrations (0.07 mg/Kg). Also, selenium in the highest concentration areas can serve as a source to groundwater, such as near soil boring RFI2SB-18 located near the former Acid

Plant. In fact, the selenium plume defined in Figure 11-9 originates in this area of the Facility.

Unsaturated Soil

The depth distribution of selenium concentrations in unsaturated soil borings collected during the Phase II RFI is shown in Table 11-6. Soil selenium concentrations are higher than saturated soils in all but one boring location (RFI2SB-20 in the Speiss Dross Area). The results also show that the highest concentrations in unsaturated soils are often associated with the occurrence of slag (i.e., samples from soil borings RFI2SB-8, RFI2SB-9, RFI2SB-10, RFI2SB-13, RFI2SB-15, RFI2SB-17, RFI2SB-18, and RFI2SB-20) (although there is high variability in selenium concentrations in the reported slag itself; <5 to 281 mg/Kg). In all locations except Tito Park (at RFI2SB-3) and the Acid Plant, selenium concentrations immediately above the water table are less than the detection limit of 5 mg/Kg. The current distribution of selenium contamination is presented and discussed in Section 6 for numerous depth intervals in Figures 6-14 (a-f).

The SPLP test results in Table 6-12 highlight the differences between arsenic and selenium solubility and the variability in soil selenium concentrations from different areas of the Facility. Overall, selenium in soils and slag is much more leachable than arsenic, by a factor of approximately 10 to 30. The soils with the highest percentage of leachable selenium are found in the Rail Corridor and Acid Plant (Figure 2-3) (median leachable percentages 4.7 and 3.4, respectively). However, rail corridor soils are quite variable with half of the samples exhibiting less than 0.3 percent leachable, suggesting that rail corridor soils are quite heterogeneous. Highest leachable concentrations of selenium occurred in rail corridor soils (up to 0.49 mg/L). Eight of the 16 soils tested (50 percent) produce leachate with selenium concentrations exceeding the MCL of 0.05 mg/L. Although the initial leachate of the Monier Flue sample (RFI2SB-6) was 0.28 mg/L, under repeated leaching, concentrations eventually decrease to below the MCL (Table 6-13).

In summary, SPLP testing suggests that although selenium concentrations in site soils are not high, at least in comparison to arsenic, the selenium in soils is in a form that is fairly leachable and capable of generating solution concentrations that exceed groundwater standards.

Slag

Concentrations of selenium in three soil samples collected from borings advanced through the slag for installation of monitoring wells DH-74, DH-75, and DH-76 are shown in Table 11-5. In all three cases, the highest selenium concentrations occur in the shallowest slag samples. At paired wells DH-74 and DH-75, selenium concentrations within the top 42 feet range from 29 to 209 mg/Kg, and at depths between 60 and 107 feet range from <5 to 14 mg/Kg. At DH-76, selenium concentrations within the top 67 feet range from 25 to 160 mg/Kg, and at depths between 60 and 107 feet, range from 10 to 33 mg/Kg.

Slag SPLP leachate concentrations and sequential extraction results are presented in Tables 6-12 and 6-14, respectively. As reported in Table 6-12, SPLP leachate concentrations (0.036 to 0.40 mg/L) indicate leachate can exceed the MCL for selenium. There is also a correlation between slag and leachate concentrations (slag sample with the lowest concentration [DH-76 at 55-62 feet; 35-57 mg/Kg] are found to generate the lowest selenium leachate concentration [0.036 mg/L]). In contrast to soils, the sequential extraction results in Table

6-14 demonstrate that operationally defined phases for selenium for the two slag samples are predominantly sulfides/selenides and residual (92 to 95 percent). The occurrence of sulfides/selenides in the slag may result from residual ore minerals that were not fully melted and/or reacted in the smelting process.

In summary, Phase II RFI data suggest that some areas of the slag may generate leachate with selenium concentrations that exceed the MCL value of 0.05 mg/L; however, to better understand the relative importance of slag loading to groundwater, natural neighbor concentration maps of total potassium (meq/L) to total cations (meq/L) were constructed at four time periods (April-May 1988; April-May 2008; May-June 2010; and October-December 2010). Potassium was selected for this analysis as a tracer of slag leachate based on measured levels in wells underlying, or adjacent to, slag (geometric mean value of 157 mg/L) that are significantly higher than process water (50 mg/L), Lower Lake (25 mg/L), groundwater in potential source areas (16 mg/L), or background groundwater (3 mg/L). As shown in Figures 11-24 (a-d), ratios are consistently highest immediately downgradient of the slag pile, and extend into an area under the City of East Helena, suggesting the presence of a slag signature in groundwater.

Other Sources

Wilson Ditch and Prickly Pear Creek are both potential sources of selenium to groundwater; however, because surface water concentrations of selenium are low in each (Figure 8-7), the primary mechanism for groundwater to be impacted is the leaching of selenium adsorbed to underlying sediment by infiltrating surface water. Table 11-3 reports surface sediment concentrations in Wilson Ditch and Prickly Pear Creek, and shows that selenium concentrations are low. This result is consistent with the low levels of selenium in groundwater in adjacent monitoring wells, and indicates that neither Wilson Ditch nor Prickly Pear Creek appear to be important current sources of selenium to groundwater.

11.2.3 Nature and Extent of Contamination

To further delineate the nature and extent of the arsenic and selenium groundwater plumes, the Phase II RFI included sampling of the existing groundwater monitoring network shown in Figure 7-1, and the installation of new monitoring wells to better delineate both the downgradient and vertical extent of contamination in offsite locations. Section 7 presents the Phase II RFI groundwater sampling results and figures showing the current distribution of contaminants in groundwater.

11.2.3.1 Arsenic

Figures 11-25 (a-d) compare the changes in the arsenic plume during four time periods (April-May 1988; April-May 2008; May-June 2010; and October -December 2010). As shown by the most recent sampling event (Figure 11-25d), the northwestern extent of 0.010 mg/L groundwater plume currently terminates at approximately 4th Avenue (Wylie Drive) and West Gail Street, which is farther downgradient than in 2000. By contrast, the northeastern extent approximately coincides with Clinton Street, which is similar to 2000. One of the biggest changes over time evident in Figure 11-25 is the onsite contraction of the highest concentration (>17 mg/L) arsenic plume (although concentrations remain above 1.7 mg/L in large areas of the Facility). Also, the Phase II RFI monitoring wells adjacent to Wilson

Ditch have identified another area where groundwater arsenic concentrations exceed 0.01 mg/L.

The vertical extent of arsenic contamination in groundwater was evaluated by comparing concentrations in paired samples along the main trajectory of the arsenic plume. The location of these samples is shown in Figure 7-1, and the results are presented in Table 11-7. The main segment of the arsenic plume onsite can be traced downgradient in Table 11-7, with concentrations relatively high and uniform with depth in the main alluvial aquifer. The low concentrations of arsenic below the Aquitard are consistent with the low soil concentrations in this unit (Table 11-4). In the offsite well cluster EH-50/EH-100/EH-103, the main high concentration arsenic plume occurs at the depth interval of 50 and 60 feet, with lower concentrations reported both above and below this depth. Finally, at the most downgradient paired wells, arsenic concentrations are below the background value.

11.2.3.2 Selenium

The selenium plume has been described as consisting of a western lobe and eastern lobe, with the two plumes joining northwest of the Facility. As shown in Figures 11-26 (a-b), these lobes of the Facility selenium plume generally range in concentrations from 0.05 to 0.1 mg/L, with two notably higher concentration areas currently centered on wells DH-66 in the western lobe and DH-6 in the eastern lobe.

Identifying the downgradient extent of selenium in groundwater was an important objective of the Phase II RFI. As shown in Figures 11-26 (a-b), the eastern offsite segment of the selenium plume is generally limited to neighborhoods underlying the City of East Helena (a result that is similar to arsenic). Although data are limited, and interpretations affected by the density of wells included in the nearest neighbor maps, this northeastern 0.05 mg/L selenium plume is similar in both 2008 and 2010. Currently, the northwest-trending selenium plume extends into Lamping Field along a trajectory that approximately parallels Prickly Pear Creek. Selenium concentrations above the background concentration (but below MCL values) occur in the northernmost residential wells sampled in 2010 (2853 Canyon Ferry Road [AEH-1012-104] and 2843 Canyon Ferry Road [AEH-1012-105]).

To distinguish between onsite sources and other selenium sources in downgradient wells, several analytes were assessed for their potential to act as diagnostic signatures of the selenium plume. The following two criteria were used during selection: (1) it was important that the analytes be at concentrations within the main plume at levels exceeding the background concentration; and (2) the analytes needed to behave conservatively. The latter is important because analytes that do not react (adsorb/precipitate) during transport should retain a relatively constant ratio to one another during dilution/dispersion. These “diagnostic ratios” often are used to identify sources of contaminants in groundwater. Concentrations of chloride and sulfate, two of the conservative analytes considered during the evaluation, are shown in Figures 11-27 (a-d) and 11-28 (a-d), respectively.

It was found that the ratios of SO_4 /total anions, Se/Cl , and Se/SO_4 provided the most separation between onsite and background (Helena Valley) groundwater signatures. As a result, nearest neighbor plume maps of these ratios were plotted in Figures 11-29 (a-d), 11-30 (a-b), and 11-31 (a-b), respectively. As shown in these figures, the 2010 distribution maps are very similar to dissolved selenium in October–December 2010 (Figure 11-26 (b)). Also, the diagnostic ratios in downgradient domestic wells during this sampling event (which

had detectable selenium concentrations of 0.027 mg/L and 0.035 mg/L, respectively) are similarly elevated relative to cross-gradient “background” ratios. This result is consistent with the hypothesis that selenium in these downgradient wells originated from Facility activities (note: one potential interpretation of the effect of seasonal flow in Prickly Pear Creek is that, during the fall, the selenium plume follows a trajectory that trends closer toward residential wells located at 2843 and 2853 Canyon Ferry Road [Figure 11-32]).

The vertical extent of the selenium plume was evaluated by comparing concentrations in paired samples along its main trajectory. The locations of the samples used in this analysis are shown in Figure 7-1, and results are presented in Table 11-7. In contrast to arsenic, selenium concentrations are relatively low in the two most-upgradient onsite wells (consistent with its low mobility in the central part of the Facility – Section 11.1.4). Selenium also is shown to be more mobile than arsenic in other locations where Se(VI) is the predominant aqueous species. For example, relatively high selenium concentrations occur below a gravel-clay unit reported in monitoring DH-15. Similar concentrations are also reported for paired offsite wells. Finally, selenium is elevated above the background concentration to depths of 160 feet at the 400 Gail Street location in the City of East Helena.

11.2.4 Fate and Transport

The Phase II RFI conducted a series of batch adsorption tests to (1) assess adsorption behavior of arsenic and selenium in different areas of the Facility, and (2) support further refinement of the groundwater transport model. These results are presented in Tables 6-15 through 6-17.

Arsenic was adsorbed by most of the soils tested with the amount of adsorption dependent on the solution concentration. The relationship between the amount of arsenic adsorbed by the soil and solution concentration (i.e., adsorption curves or isotherms) also was evaluated by three commonly used equations: Freundlich Equation, Langmuir Equation, and a linear equation. Parameters for each of these equations are reported in Appendix 11-B; Appendix 11-C includes adsorption test results from Hydrometrics (2005).

None of the 17 soil samples tested demonstrated any capacity for selenium adsorption with any of the three groundwater solutions, which varied in concentration from 0.118 to 5.32 mg/L. In virtually all of the tests, selenium was leached from the soils by the groundwater solutions. These results are consistent with the presence of Se(VI) (which is highly soluble); however, the high concentrations of arsenic used in the tests (1.56 to 3.1 mg/L) complicates interpretation. As discussed in GSI (2011), there are a finite number of adsorption sites available for sequestration on aquifer materials. In cases where groundwater arsenic concentrations greatly exceed selenium, there will be little available capacity for selenium adsorption. Batch adsorption tests using groundwater from locations where selenium concentrations are higher than arsenic (EH-138 and EH-139) reported some selenium adsorption at the highest solid-to-solution ratio.

11.3 Current Groundwater Geochemistry

This section incorporates Phase II RFI data into a conceptual model of groundwater geochemistry beneath and adjacent to the Facility, with respect to major ion concentrations, pH, ORP, organic parameter concentrations, and contaminant plume geometry. Current

groundwater quality is described on the basis of recent groundwater monitoring results and regional studies for background (unimpacted) groundwater, Facility impacted groundwater, and downgradient areas where Facility effects are gradually mitigated by both physical (mixing, dilution, dispersion) and geochemical processes. Significant temporal changes in groundwater quality beneath and downgradient of the Facility since the initiation of monitoring during the RI/FS also are evaluated.

The groundwater geochemistry in the vicinity of the Facility is influenced by background (naturally occurring) water chemistry from a variety of sources, with Facility impacts apparent in groundwater beneath and downgradient of the Facility. A summary of the current major ion (calcium, magnesium, sodium, potassium, chloride, bicarbonate, carbonate, and sulfate) groundwater chemistry in the area is shown in Figure 11-33, using Stiff diagrams to distinguish various local and regional water types, including representative chemistries for both impacted and unimpacted groundwater (Stiff diagrams present major ion composition as a polygon, with vertices located along a horizontal axis proportional to the relative concentrations of major ions in milliequivalents per liter, allowing for rapid visual comparison of predominant cations and anions). A complete set of Stiff diagrams for all site monitoring wells and selected surface water sampling locations is included for reference in Appendix 11-D. Diagrams are included for both historical and recent groundwater samples for comparison.

11.3.1 Unimpacted Groundwater

The geochemical signature of background (unimpacted by Facility activities) shallow alluvial groundwater in the vicinity of the Facility is probably best represented by monitoring well DH-3, located south of the Facility adjacent to Upper Lake (Figure 7-1). This groundwater is characterized as a calcium-bicarbonate type with neutral pH. Shallow wells recently sampled farther south of the Facility at the 690 Smelter Road residence (water supply to the corral), and at the Hidden Valley trailer park (water supply wells 1 and 2) show water quality very similar to that observed at DH-3. Average major ion concentrations during the monitoring period for DH-3 and the referenced private wells are 62 mg/L calcium, 14 mg/L magnesium, 24 mg/L sodium, 5.4 mg/L potassium, 13 mg/L chloride, 203 mg/L bicarbonate, and 71 mg/L sulfate (Table 11-8). Major ion concentrations have remained stable over time at DH-3.

Additional contributions to shallow groundwater in the vicinity of the Facility occur via leakage and infiltration from Prickly Pear Creek and Upper Lake (which represents impounded Prickly Pear Creek water). Prickly Pear Creek monitoring site PPC-3A, located immediately upstream of the Facility (Figure 9-1), has been monitored since 1996 and shows calcium-bicarbonate water quality similar to, but slightly more dilute than, alluvial groundwater. Average major ion concentrations in Prickly Pear Creek during the last 14 years include 26 mg/L calcium, 6 mg/L magnesium, 12 mg/L sodium, 2 mg/L potassium, 3.5 mg/L chloride, 83 mg/L bicarbonate, and 41 mg/L sulfate (Table 11-8). Field-measured pH values at this site have ranged from 6.2 to 9.2 (laboratory-measured values have ranged from 6.6 to 8.2). Some seasonal variability in concentrations is apparent in Prickly Pear Creek, reflecting a higher percentage of flow from dilute runoff during higher precipitation (spring) periods (TDS concentrations have ranged from 96 to 211 mg/L during the period of

record). However, no long-term trends in water quality are apparent in Prickly Pear Creek upstream of the Facility.

In addition to the shallow alluvial system, groundwater is also occasionally present in local Tertiary sediments. Well EH-203, installed west of the Facility in 2010 (Figure 7-1), is completed in Tertiary material, and shows a calcium-bicarbonate signature with a moderate dissolved solids concentration (about 300 mg/L TDS in two samples collected in 2010). Other wells completed in Tertiary sediments farther to the west, however, show a distinctive magnesium component; site-related monitoring wells showing this geochemical signature include EH-200 and EH-201 south of Highway 12, EH-209 north of Seaver Park, and EH-139 north of Lamping Field (Figure 7-1). In general, groundwater at EH-139 is slightly lower in concentration than the other three wells, perhaps indicating higher contribution from alluvial groundwater or Prickly Pear Creek water at this location. Major ion concentrations at wells EH-200, EH-201, and EH-209 (all installed in 2010) have averaged 52 mg/L calcium, 33 mg/L magnesium, 33 mg/L sodium, 6 mg/L potassium, 24 mg/L chloride, 294 mg/L bicarbonate, and 82 mg/L sulfate (Table 11-8). The magnesium-bicarbonate signature shown at wells EH-200, EH-201, and EH-209 is also apparent at residential wells in the southwestern portion of Seaver Park, including the wells at 2700 Winslow, 2705 Winslow, and 2715 Winslow (Figure 7-1). A spring located southwest of wells EH-200 and EH-201 (denoted the R&D Spring upstream) also showed the magnesium-bicarbonate water type. These results suggest that this water type may be a good indicator of Tertiary groundwater influence as flow from these sediments merges with shallow Quaternary alluvial groundwater northwest of the Facility (e.g., at well EH-139).

The geochemistry of groundwater derived from bedrock in the Helena area was reviewed by the USGS (Thamke, 2000). Although no bedrock wells were sampled near the Facility as part of the USGS study, the report noted that water from bedrock in the South Hills area south and west of the Facility was generally of calcium-bicarbonate or mixed cation bicarbonate type, with calcium-bicarbonate waters derived from granitic rocks and mixed cation-bicarbonate waters derived from the Helena Formation (dolomitic argillite and siltite). Groundwater derived from the Spokane Formation, also predominantly argillite and siltite, is typically calcium-bicarbonate or mixed cation-bicarbonate. A groundwater sample collected about 10 miles west of the Facility (presented in Table 11-8) and reported by Thamke (2000) shows mixed cation-bicarbonate chemistry, with a relatively high sulfate concentration (100 mg/L) and a significant magnesium component, similar to the Tertiary wells west of the Facility.

Water chemistry data, presented in (Appendix 7-G), show that the general water chemistry in well DH-3 is significantly more concentrated than in Upper Lake, however the water types are the same (calcium sulfate). The general water chemistry in DH-3 is approximately the same in May 2009 and October 2010, where Upper Lake shows large fluctuations in general water chemistry, which can be attributed to dilution from spring runoff. The difference in concentration and fluctuations suggests that although the water level elevations correlate and it appears the water level at DH-3 is controlled by Upper Lake, the general chemistry at DH-3 suggests that groundwater in this area may be recharged by multiple sources.

11.3.2 Facility Groundwater

The groundwater beneath the Facility has been impacted by Facility operations during the operational history of the Facility through 2001 (shutdown), and groundwater quality impacts continue to be observed. These impacts are apparent in both major ion and trace constituent groundwater concentrations, as well as in areas of elevated or depressed pH. A zone of organic contamination is also present within the central portion of the Facility, which likely affects the redox state of groundwater, and thus the transport properties of the redox-sensitive constituents of concern, arsenic and selenium.

Previous investigations at the Facility, from the RI/FS (Hydrometrics, 1990) through the *Phase I RFI* (Hydrometrics, 2005), have identified historical source areas of contaminant loading to groundwater (see Section 11.1.2). In general, the primary source areas identified to date include the Speiss/Dross Area, the Acid Plant Water Treatment and Sediment Drying Areas, the Lower and Upper Ore Storage Areas, Lower Lake, and the Slag Pile (Figure 2-3). Local soils and groundwater chemistry have been impacted in a range of ways depending on specific Facility processes or past disposal practices. The current general geochemistry of Facility groundwater in key areas is summarized below.

11.3.2.1 Acid Plant Area

Groundwater in the acid plant area (represented by well DH-42, most recently sampled in October 2010) continues to show a slightly acidic pH (6.0) and an elevated sulfate concentration (350 mg/L) relative to area the background value. Cation concentrations at well DH-42 also are elevated compared with background alluvial groundwater concentrations (Tables 11-9 and 11-8, respectively). The pH at nearby well DH-19R in November 2009 (Appendix 7-G) confirms the persistence of a low pH area of groundwater of limited extent in the acid plant area. Groundwater chemistry in the acid plant area reflects residual impacts of acidic process water releases and disposal of acid plant sediments in the APSD Area, which was encapsulated within a slurry wall in 2006.

11.3.2.2 Lower Lake

Lower Lake water is currently a sodium-sulfate type with slightly alkaline pH (Table 11-9). Concentrations of major constituents (as well as arsenic and selenium) in Lower Lake have decreased substantially since plant shutdown in 2001 (see Section 11.2.2). Lower Lake receives discharge of treated stormwater from the Facility HDS plant, and thus the present water chemistry of Lower Lake is impacted by both stormwater runoff quality and reagents added during the treatment process.

11.3.2.3 Slag Pile

The slag pile covers the northeastern part of the Facility south of Highway 12 and west of Prickly Pear Creek. Wells completed through the slag exhibit variable water chemistry, particularly in a north-south direction. The wells located near the south end of the slag pile (DH-68, DH-69, and DH-76) show lower concentrations of both major ions and contaminants (arsenic and selenium) along with indications of moderately reducing conditions (soluble iron concentrations >8 mg/L, soluble manganese concentrations >2 mg/L, and dissolved oxygen concentrations <0.3 mg/L). As shown in Table 11-9, wells at the southern end of the slag pile (represented by well DH-69) show a sodium-bicarbonate signature, and do not show elevated sulfate concentrations. Sulfate concentrations at these

wells (<10 mg/L) are typically much lower than the background values suggesting that sulfate reduction may be occurring under the predominantly reducing groundwater conditions. The reducing conditions in groundwater at the south end of the slag pile may be attributable to interactions with organic-rich historical marsh deposits present in the Prickly Pear Creek floodplain that was buried beneath the slag pile.

At the north end of the slag pile (represented by wells DH-55, DH-56, and DH-74), groundwater appears to become more oxidizing. Iron and manganese concentrations are near or below detection limits in these wells, although dissolved oxygen concentrations remain relatively low. Significant changes in major ion chemistry also occur in the northern slag pile wells. Water chemistry from well DH-56 for October 2010 (Table 11-9) shows high concentrations of sodium (482 mg/L), potassium (473 mg/L) and sulfate (1400 mg/L). Arsenic and selenium concentrations are also higher in the northern slag pile wells than in the southern slag pile wells (Figures 11-25d and 11-26b). Geochemical equilibrium calculations indicate that, at the concentrations shown in Table 11-9 for well DH-56, several carbonate minerals are slightly oversaturated, which may indicate precipitation of these species is occurring. Despite the high sulfate concentration (1400 mg/L), sulfate minerals such as gypsum (calcium sulfate) remain undersaturated in the northern slag pile wells.

11.3.2.4 Upper Ore Storage Area

Groundwater quality in the former Upper Ore Storage Area between Upper Lake and Lower Lake is monitored by a number of APSD-series wells installed as part of the investigation of the acid plant sediment drying area in the western portion of this area, now encapsulated in a slurry wall. Wells APSD-9, APSD-11, and APSD-12 all currently show calcium-bicarbonate type water, with slightly elevated sulfate concentrations (Table 11-9). Well APSD-10, located closer to the historical APSD area, shows significantly higher calcium (243 mg/L in November 2009) and sulfate (600 mg/L in November 2009) concentrations than the other APSD wells in the Upper Ore Storage Area (and outside the slurry wall), along with higher arsenic concentrations in groundwater.

11.3.2.5 Lower Ore Storage Area

Two wells on the eastern edge of the historical Lower Ore Storage area (DH-8 and DH-66) currently show the highest concentrations of selenium at the Facility. These wells show elevated concentrations of all major ions, and are unusually elevated in chloride, calcium, and magnesium compared with other Facility wells (Table 11-9). Similar to the other high-sulfate groundwater present at the north end of the slag pile, geochemical speciation results for the December 2010 results for well DH-8 in Table 11-9 show this water to be slightly oversaturated for calcite, but undersaturated with respect to gypsum. Groundwater in the central portion of the Lower Ore Storage area (well DH-62), while elevated in most major ion concentrations (Figure 11-33), does not show the anomalously high chloride concentration observed at wells DH-8 and DH-66.

11.3.2.6 Speiss/Dross Area

The historical Speiss/Dross Area in the central portion of the Facility was encapsulated in a slurry wall in 2007. This area historically showed elevated pH (>10) and very high concentrations of both major ions and arsenic and selenium. The most recent sample from well DH-21, among the most impacted wells on the Facility, was collected in November 2009, and showed that elevated pH persists in this area (9.8), along with the highest

concentrations of sodium (1,070 mg/L) and bicarbonate (1,100 mg/L) observed at the Facility. In addition, the calcium and magnesium concentrations at well DH-21 (both 4 mg/L) are unusually low; this could be an indication of calcite/dolomite precipitation in this area.

Current data for wells adjacent to, but outside of, the speiss/dross area slurry wall (SDMW-1, SDMW-3, SDMW-5) show that all three wells also exhibit sodium-sulfate type groundwater, although concentrations of sodium (83 to 163 mg/L) and sulfate (290 to 400 mg/L) are much lower than within the slurry wall. Well SDMW-1, north of the slurry wall (Figure 11-33) is the only one of these three wells to show sulfate and bicarbonate concentrations in a ratio roughly proportional to that observed at well DH-21 (250 mg/L bicarbonate and 290 mg/L sulfate in October 2010). In addition, all three of these wells typically show pH values <7, with wells SDMW-3 and SDMW-5 in the 5 to 6 pH range, indicating that the ongoing elevated groundwater pH regime is apparently confined within the slurry wall.

11.3.2.7 Organic Constituents

Monitoring for organic constituents in groundwater (and soils) beneath the Facility has occurred sporadically from the late 1980s through the present. Historically, analyses were conducted for general parameters such as oil and grease, total petroleum hydrocarbons, diesel range organics (DRO), and gasoline range organics (GRO), with occasional analysis for specific volatile or semi-volatile compounds. Data for VPHs and EPHs were collected during the Phase II RFI for soil samples exhibiting signs of organic contamination during field sample collection (see results in Table 11-10).

Previous investigations have noted an extensive area of organics contamination of soils near the water table through the central Facility, approximately from well DH-30 in the southeast to well pair DH-16/DH-17 in the northwest (Figure 11-33). This area of organics contamination coincides with a low groundwater redox zone indicated by arsenic speciation, dissolved oxygen, and field ORP measurements, and with the historically high concentration region of the groundwater arsenic plume. Groundwater concentrations as high as 492 mg/L DRO (in 1996) and 108 mg/L GRO (in 1997) have been observed at well DH-27 upgradient of the speiss/dross slurry wall; evidence of organic parameter migration off the Facility at well EH-60 also has been observed as recently as 2001 (GRO concentration of 60 mg/L). These results are typical of wells throughout the central Facility, with moderate to high concentrations of largely heavier range organic constituents present in groundwater.

Analysis of Phase II RFI soil boring samples confirmed the persistence of heavy range hydrocarbon contamination in the subsurface throughout the central Facility. Phase II RFI soil borings RFI2SB-7, RFI2SB-16, RFI2SB-17, RFI2SB-20, and RFI2SB-21 all showed field evidence of organic contamination near the water table, and VPH/EPH analysis showed concentrations of total extractable hydrocarbons (TEH) in soils from these borings ranging from 405 mg/Kg at RFI2SB-17 to 7,000 mg/Kg at RFI2SB-20. The TEH fraction of organics represents heavier hydrocarbons, while total purgeable hydrocarbons provide a general measure of lighter (gasoline range) organics. While total purgeable hydrocarbons were detected in the Phase II RFI soil samples, the observed concentrations were significantly lower than the TEH fraction (23 to 188 mg/Kg). Ongoing slow degradation of heavy

hydrocarbons throughout the central Facility area likely impacts groundwater redox conditions, and thus the speciation of (and fate and transport characteristics of) the redox-sensitive contaminants arsenic and selenium.

11.3.2.8 Summary

Overall, the current general geochemistry of groundwater beneath the Facility (summarized in Table 11-9 and in Figure 11-33) illustrates a wide range of water compositions and complex geochemistry, resulting from the interaction of groundwater impacted by historical process water releases, as well as, potentially ongoing releases from site soils. Large differences in water chemistry can occur over relatively short lateral or downgradient distances. In certain areas, large seasonal variations also are observed. The primary conclusions of the Facility groundwater geochemistry review can be summarized as follows:

- Areas of both low pH and high pH persist in groundwater near the historical Acid Plant and the Speiss Dross Area, respectively. However, these areas are apparently of limited spatial extent, and the high pH speiss/dross influenced groundwater appears to be entirely contained within the speiss/dross slurry wall.
- Significant differences in parameter concentrations and groundwater geochemical composition are observed between wells located on the southern end of the slag pile and the northern end of the slag pile. South slag wells are characterized by slightly elevated sodium, very low sulfate, and reducing conditions (elevated iron and manganese). North slag wells are more oxidizing (very little or no soluble iron and manganese), and show distinctively elevated potassium concentrations (>400 mg/L), along with high sodium (>400 mg/L) and sulfate (>1,000 mg/L) concentrations.
- Chloride concentrations in wells located in the Lower Ore Storage Area wells DH-8 and DH-66 show unusually elevated chloride concentrations compared with the rest of the Facility (>300 mg/L) [if this is the concentration for the wells, it's in the wrong part of the sentence]. Sulfate concentrations also are elevated (1,000 to 2,000 mg/L), along with calcium (>500 mg/L) and magnesium (>100 mg/L).
- The Speiss/Dross Area (represented by well DH-21) continues to show very high sodium and bicarbonate concentrations (>1,000 mg/L), and elevated sulfate concentrations (>800 mg/L). In addition, calcium and magnesium concentrations at this well are quite low (4 mg/L). The effect of this groundwater chemistry on the chemistry of water currently migrating off the Facility, however, is unclear, because the entire speiss/dross area is contained within a slurry wall. Sample results from wells adjacent to, but outside of, the slurry wall (SDMW-1, SDMW-3, and SDMW-5) would suggest that the spatial extent of impacts from Speiss/Dross Area groundwater via direct migration might be limited.
- Consistent with historical results, Phase II RFI soil boring analyses indicate the continued presence of heavy hydrocarbon contamination in the subsurface throughout the central Facility, from RFI2SB-7 south of the speiss/dross slurry wall, to RFI2SB-21, north of the main Facility area near the property boundary with American Chemet. Continued degradation of hydrocarbons in this area likely

exhibits significant control on groundwater redox conditions, and thus the groundwater fate and transport behavior of arsenic and selenium.

11.3.3 Downgradient Groundwater

The influence of site groundwater on downgradient locations is illustrated by the Piper diagram shown in Figure 11-34. A Piper diagram depicts either cation or anion data as milliequivalent percentages of the major ions typically found in groundwater. The closer a particular groundwater sample plots to one of the apices of a triangle, the greater the relative abundance of that respective ion in the groundwater sample. Figure 11-34 shows that downgradient offsite groundwater largely plots between regional and Facility process waters, suggesting it is a mixture of the two (USGS, 1985). As shown in Figure 11-33 and Table 11-11, characteristics of Facility groundwater (particularly elevated concentrations of sodium, sulfate, and chloride) are evident at the farthest downgradient monitoring well (EH-138).

Downgradient of the Facility, arsenic and selenium plumes from historical Facility activities are moderated as alluvial groundwater/Prickly Pear Creek water from the east and unimpacted (Tertiary) groundwater from the west mix with the contaminant plume. The plume of impacted groundwater migrating from the Facility appears to be relatively narrow and constrained laterally (Figures 11-25d and 11-26b). However, major ion concentrations above background levels persist in a downgradient (northwest) direction, and remain elevated at the current downgradient limit of monitoring well coverage (Phase II RFI wells EH-138 and EH-139).

11.4 Groundwater Transport of Arsenic

This section incorporates Phase II RFI data into a revised conceptual model of arsenic fate and transport in groundwater that includes an updated evaluation of contaminant sources to groundwater (Section 11.4.1), a reassessment of the current conceptual model of arsenic mobility (Section 11.4.2), and a plume stability analysis (Section 11.4.3).

11.4.1 Areas of Potential Concern

As discussed in Section 11.1.2, potential source areas to groundwater include water and sediment of Lower Lake, saturated and unsaturated soils in historical processing/storage areas, and slag. Results from the Phase II RFI data indicate the following with respect to these sources:

- Surface water in Lower Lake is an ongoing low-level (0.1 mg/L) source of arsenic to groundwater; however, the lake is not a major source, as these concentrations are significantly less than downgradient monitoring wells. By contrast, because Lower Lake surface sediment has elevated levels of arsenic (historically high arsenic loading from Lower Lake surface water), it may be an important source of arsenic in groundwater (through a process of leaching by the infiltrating Lower Lake surface water). Additional sampling and characterization would be required to evaluate sediment as a source.
- Saturated zone soils appear to be a significant ongoing source of arsenic loading to groundwater in the southern half of the Facility, particularly the Acid Plant, Speiss-

Dross, and Tito Park areas. Sequential leach tests verify that arsenic is leached from soils at concentrations that exceed the MCL. The thickness of arsenic contamination in saturated soils extends to more than 20 feet in some areas.

- Unsaturated zone soils may be a source of loading to groundwater in certain areas of the Facility. High concentrations of arsenic in SPLP leachate were obtained at soil boring RFI2SB-18 near the acid plant (2.0 mg/L), and RFI2SB-3 in Tito Park (2.4 mg/L), both of which have relatively shallow groundwater. Because SPLP leachate concentrations were less than 0.2 mg/L elsewhere, leaching of unsaturated zone soils at environmentally significant arsenic concentrations may not be as significant outside of these primary areas. In onsite downgradient areas (where the water table is deep) there appears to be unused sorption capacity to inhibit vertical arsenic migration to groundwater.
- Unsaturated slag also was found to produce leachate at concentrations that exceed the arsenic MCL in three of the four samples tested. These results indicate slag has a potential to generate arsenic concentrations similar to those observed downgradient of the slag in the City of East Helena. The concentration of arsenic in slag is highly variable, and leach tests were conducted on samples with the highest concentrations, so the maximum SPLP leachate of 0.4 mg/L, may represent an upper estimate of leachate arsenic concentrations.

11.4.2 Mobility in Groundwater

A principal control on arsenic mobility in groundwater is the redox state of the aquifer, as redox directly affects the stability of minerals that sequester arsenic (Section 11.1.4). The Phase II RFI included additional characterization of redox-sensitive parameters in groundwater, and also performed sequential extraction and batch adsorption tests to quantify the adsorption process. Results include the following:

- The hypothesis that redox conditions affect arsenic mobility in groundwater is consistent with the presence and distribution of dissolved constituents measured during the Phase II RFI. Figures 11-35 (a-c) and 11-36 (a-c) show that As(III) historically has been the primary chemical form of arsenic released from onsite sources, but this species is transformed to As(V) downgradient (note that As(V) now predominates in many areas onsite and most areas offsite). Although the release of As(III) and other chemically reduced species (such as Fe(II)) in groundwater has contributed to an onsite depression in Eh (Figure 11-37), more oxidizing redox conditions occur offsite, presumably because of mixing of the plume with oxygenated water and buffering by aquifer minerals. The net result of this oxidation is the removal of dissolved iron (via mineral precipitation) from groundwater (Figures 11-38 (a-d), and the sequestration of arsenic through adsorption/co-precipitation. The presence of manganese oxides in the downgradient aquifer is also important because these minerals will oxidize As(III) (Han et al., 2011). Groundwater data supporting the reaction between As(III) and Mn(IV) include the high dissolved manganese levels that extend beyond the offsite As(III) plume (Figures 11-39 [a-c]). Trends in pH (with depressed pH mirroring the arsenic plume (Figures 11-40 [a-c]) are consistent with oxidation reactions in the arsenic plume.

- Batch adsorption tests verify that there is a high capacity for arsenic adsorption by aquifer materials. Sequential extraction tests conducted on soils from onsite areas demonstrates that arsenic is associated with several operationally defined fractions that vary by location. Included are three fractions (exchangeable, amorphous oxides, and crystalline oxides) present in most soils that are likely associated with iron oxide minerals (these mineral phases are indicated to be present even in relatively reducing areas, such as the Acid Plant).

11.4.3 Arsenic Plume Stability

The stability of the arsenic plume was assessed by comparing changes in arsenic concentrations over time. Soil and groundwater profiles also were constructed from Phase II RFI data to understand the vertical migration of arsenic. A summary of these results includes the following:

- As discussed in the *Phase II RFI Work Plan* (Hydrometrics, 2010a), the arsenic plume appears to be relatively stable, with little expansion during the last 8 to 10 years in downgradient extent. Concentrations at some wells show decreasing trends for arsenic; however, decreases have not been proportional to decreases in other site indicators, such as sulfate. Ongoing loading to groundwater is indicated by adsorption/leach test results. For example, the 40- to 42-foot interval of soil from boring RFI2SB-16 was tested for arsenic adsorption capacity using an initial solution concentration of 1.56 mg/L; however, rather than adsorbing arsenic, this sample leached a significant quantity of arsenic, with a final post-equilibration solution concentration of 5.8 mg/L.
- The limited migration of the arsenic plume is probably to the result of the high adsorption capacity of soils downgradient of the Facility for arsenic. Adsorption testing of soils from Lamping Field wells downgradient of the current arsenic plume showed 89 to 99 percent adsorption of arsenic from solution after 72 hours of equilibration time at a 1:4 soil:solution ratio, given an initial arsenic solution concentration of 3.1 mg/L (water obtained from well EH-111). Samples from locations closer to the primary arsenic plume, such as soil boring RFI2SB-21, also showed adsorptive capacity, although the historical loading of arsenic onto these materials and the diminished adsorptive capacity was apparent in the batch adsorption results. A sample from the 30- to 52-foot interval at RFI2SB-21 showed 47 percent adsorption of arsenic from solution at an initial concentration of 1.56 mg/L (DH-6 water).
- The depth-distribution of arsenic in saturated soils shows that arsenic has not appreciably penetrated the underlying Aquitard, consistent with the current conceptual model (see Table 11-3).

11.5 Groundwater Transport of Selenium

This section incorporates Phase II RFI data into a revised conceptual model of selenium fate and transport in groundwater that includes an updated evaluation of contaminant sources to groundwater (Section 11.5.1), a reassessment of the current conceptual model of mobility (Section 11.5.2), and a plume stability analysis (Section 11.5.3).

11.5.1 Areas of Potential Concern

As discussed in Section 11.1.2, potential selenium source areas include water and sediment of Lower Lake, saturated and unsaturated soils in historical processing/storage areas, and slag. Phase II RFI results with respect to these sources are summarized below. Because the selenium plume generally consists of a western lobe (west selenium plume) and eastern lobe (east selenium plume) at the Facility (with the two plumes joining northwest of the Facility – Figures 11-26 (a-b)), these areas are discussed separately.

11.5.1.1 West Selenium Plume

- As discussed in Section 11.1.2, previously collected soil and groundwater selenium data suggest that the current groundwater selenium plume may be a transient plume, resulting from historical process water-related sources. Evidence that supports this hypothesis are the reportedly high concentrations of selenium in process water (Hydrometrics, 2010a), as well as, maximum site concentrations of selenium that coincide with sulfate (the latter being an indicator of Facility process water) (Figures 11-26b and 11-28d).

Data that confound this interpretation are the ongoing occurrence of elevated chloride and sulfate at well DH-8/66 (Appendix 7-G), 10 years after Facility shutdown (since all process water releases should have ceased, and 10 years would necessarily be adequate for the last remnants of conservative constituents, such as chloride and sulfate, to migrate beyond their current locations in the west selenium plume). The high concentrations of chloride, sulfate, and selenium, and the recent trends of increasing concentrations (perhaps with recent decreases for chloride) may suggest an ongoing or recent source for selenium, rather than a transitory historical release of process water migrating through the groundwater system.

- Because soil selenium leachate concentrations from the Phase II RFI are less than those reported in the vicinity of the thaw house and CSHB (1 to 3 mg/L), existing data do not indicate that saturated soil is the source of the highest concentrations in the west selenium plume. However, saturated soil may be the source of the lower concentration portions of the plume. For example, significant desorption/release of selenium from soils to leach water was indicated in samples from the acid plant area (RFI2SB-18; selenium in soil of 76 to 94 mg/Kg, and selenium in leachate of 0.13 to 0.21 mg/L).
- Unsaturated zone soils may be a source, at least in part, of the lower concentration portions of the west selenium plume. This is based on the relatively high selenium concentrations found in soils at surface soil sampling locations RCSS-5 and RCSS-7, and soil boring RFI2SB9, upgradient of the thaw house and CSHB (sample locations shown in Figure 11-15). Leach testing shows that unsaturated zone soils in this area may leach selenium in significant quantities, with leach results ranging from 0.027 to 0.49 mg/L selenium (SPLP results). Although the leach test data show that local unsaturated soils contribute to higher selenium concentrations in the west selenium plume hot spot, this process does not fully explain the selenium concentrations and other geochemical trends observed at these wells. Accompanying the higher

selenium concentrations in this area are higher concentrations of sulfate and chloride, both indicators of Facility process waters (Figures 11-26 [a-b] and 11-27 [a-b], respectively).

11.5.1.2 East Selenium Plume

- Historical HDS effluent data show that selenium was elevated in HDS plant effluent from 1998 to 2001 (concentrations ranging from 0.5 to 2.3 mg/L), similar to the effluent sulfate trend. Subsequent data for Lower Lake and 2007-2010 HDS effluent also show that selenium concentrations are generally similar between the two, so previous Lower Lake selenium concentrations (1998 to 2001) were probably similar to the historical HDS effluent data (HDS plant discharge during plant operations in the 1998-2001 period was greater than it currently is, so HDS plant effluent probably had an even stronger influence on Lower Lake chemistry [and downgradient groundwater] than it currently does). This line of evidence indicates that Lower Lake likely had elevated selenium concentrations through 2001, with concentrations potentially ranging from 0.5 to 2.3 mg/L during this period. The sudden decrease in Lower Lake selenium concentrations after 2001 correlates with the decrease in sulfate and chloride concentrations. Therefore, Lower Lake was apparently a source of selenium, chloride, and sulfate to groundwater through 2001.
- Slag is capable of leaching significant selenium concentrations, although variability throughout the slag pile is high. SPLP leachate concentrations from slag samples range from 0.036 to 0.40 mg/L, with the highest concentrations obtained from a deeper sample (40 to 42 feet at well DH-74). The higher leachable concentrations of selenium from slag correlated with higher total concentrations of selenium in slag, and the higher total concentrations of selenium appear to be associated with the central upper lift of the slag pile. This portion of the slag pile is the newest, perhaps reflecting a change in feed ore chemistry during the most recent operational period before Facility shutdown. The spatial distribution of selenium in groundwater in the east selenium plume is consistent with slag as a potential source, given that the elevated concentrations occur only to the north (downgradient) of the upper lift. Concentrations closer to Lower Lake are typically at or below detection limits. Additional evidence for slag as a potential source of selenium is that the eastern selenium plume also shows very high potassium concentrations (>400 mg/L), which is considered a tracer of slag leachate. Relative concentrations of potassium to other cations downgradient of the slag pile have remained elevated over time (Figures 11-24 [a-d]).

11.5.2 Mobility in Groundwater

A principal control on selenium mobility in groundwater is the redox state of the aquifer. As discussed in Section 11.1.4, redox directly affects selenium speciation, with solubility increasing in the order $\text{Se}(0) < \text{Se}(\text{IV}) < \text{Se}(\text{VI})$. The Phase II RFI conducted additional characterization of redox-sensitive parameters in groundwater, and also conducted sequential extraction and batch adsorption tests to quantify the adsorption process. Results include the following:

- The hypothesis that redox conditions affect selenium mobility in groundwater is consistent with the presence and distribution of dissolved constituents measured during the Phase II RFI. Figures 11-41a and 11-41b show that except for the high concentration area in the west selenium plume and maybe a small area near the acid plant, the predominant chemical form of selenium in groundwater is Se(VI), which means selenium will be highly mobile. Supporting evidence for the high mobility of selenium includes the similarity in plumes for selenium, sulfate, and chloride, particularly offsite.
- Additional sampling and analysis also was conducted to test for hydrocarbons in the central portion of the Facility. Analysis of Phase II RFI soil boring samples confirmed the persistence of heavy range hydrocarbon contamination in the subsurface throughout the central Facility (Figure 6-16). Thus, ongoing slow degradation of heavy hydrocarbons throughout this area is likely impacting groundwater redox conditions, and thus the speciation of (and fate and transport characteristics of) the redox-sensitive contaminants. In the case of selenium, reducing conditions could lead to the stability of insoluble forms, such as elemental selenium Se(0). This, in turn, may partly explain the separation of the selenium plume into the eastern and western lobes.

11.5.3 Selenium Plume Stability

The stability of the selenium plume was assessed by comparing time series on wells with historical data. Also, the current extent of the plume was examined using diagnostic ratios (Section 11.2.3). Results include the following:

- Historical data for selenium in groundwater are limited in both spatial and temporal coverage. However, the available data suggest that selenium concentrations in Facility groundwater have increased significantly in the recent past (compared with the overall operational history), sometime between 1985 and 1998. For example, of the wells with selenium data from 1985, five show apparent increases in concentrations between 1985 to 2010, including: DH-1 (west Facility boundary near Wilson Ditch), DH-6, and DH-10/10A (north of the slag pile), DH-8 (near the ore storage building), and DH-9 (near the former zinc plant) (Figures 11-19 through 11-21). The six remaining wells show little or no change in selenium concentrations between 1985 and 2010 (Appendix 7-G). The most significant changes in selenium concentration are observed at wells DH-6 and DH-8, where median concentrations changed by 2 orders of magnitude between 1985 and the present. These locations also represent the areas of current highest concentration at the Facility (Figure 11-26b).
- The relatively low selenium concentrations recorded during the first historical sampling events in the early 1980s suggest that selenium was present at significantly lower concentrations at the Facility than its present-day distribution. This hypothesis is supported by changes in operational history of the Facility and selenium concentrations in slag that are highest in the most recently disposed materials. A relatively recent selenium plume is important because it suggests that the lateral extent of that portion of the plume exceeding the MCL (0.05 mg/L) has already been fully delineated. Furthermore, the co-located sulfate plume may be

useful for determining dilution and dispersion in the aquifer because a relatively complete flux history of sulfate is more easily constructed for this time period (1985 to present). The occurrence of selenium at 120 feet depth at 400 Gail Street in the City of East Helena indicates there is a significant vertical component of the plumes offsite, which would contribute to dilution.

- The mapped downgradient extent of selenium with a Facility source-signature is currently the residential wells located at 2843 and 2853 Canyon Ferry Road (AEH-1012-104 and AEH-1012-105). Reported concentrations at these wells are 0.027 mg/L and 0.035 mg/L, respectively (Figure 11-32). Whether the currently defined 0.05 mg/L selenium plume reaches these downgradient locations most likely will depend on physical processes of dilution and dispersion because attenuation of the dominant aqueous species (Se(VI)) is expected to be small.

12 Groundwater Flow and Contaminant Transport Model

This section presents a summary of previous modeling efforts and discusses the current development and use of a groundwater flow and contaminant transport model to evaluate conditions at the Facility and to support development of the CMS.

12.1 Summary of Previous Investigations

Asarco previously developed a numerical groundwater flow and transport model for the Facility as part of the *Comprehensive RI/FS* (Hydrometrics, 1990). The model was used to evaluate the migration of arsenic from process-water-related sources and the potential for long-term releases from soils. This model evaluated only arsenic fate and transport, and did not attempt to simulate other contaminants, most notably selenium.

The 1990 transport model used retardation coefficients to simulate geochemical attenuation of arsenic in the groundwater system. This effectively slowed down the rate of arsenic transport in the model to account for temporary sorption of arsenic on aquifer material. This method of simulating geochemical attenuation assumes that all arsenic attenuation is completely reversible (i.e., all arsenic that is attenuated or removed from groundwater by soils is later released to groundwater). However, sequential extraction analyses of site soils (conducted as part of the *Comprehensive RI/FS*) indicate that arsenic attenuation on the Facility site is not completely reversible and that a significant portion of the arsenic is present in stable phases that are not easily remobilized. Because complete reversibility was assumed in the model, the *Comprehensive RI/FS* concluded that the model was overly conservative in its assessment of the long-term potential for arsenic migration in groundwater.

After completing the *Comprehensive RI/FS*, Asarco implemented several corrective measures to reduce or eliminate process water sources and collected additional groundwater geochemistry data. The 1990 transport model was updated for the *Phase I RFI* (ACI, 2005) to include soil-related source terms. This required further examination of soil leachability and arsenic attenuation mechanisms. The *Phase I RFI* model concluded that the arsenic plume in the shallow groundwater system would move approximately 150 feet during a 50-year period.

12.2 Phase II Investigation

In the years since the *Phase I RFI* modeling effort was completed, additional investigations have been conducted that provide further information on aquifer characteristics and the fate and transport of arsenic and selenium. In addition, corrective actions (e.g., installation of slurry walls, placement of temporary caps, building demolition, and testing of a pilot-scale permeable reactive barrier [PRB]) have been implemented that have altered Facility groundwater conditions. The 1990 *Comprehensive RI/FS* model and the *Phase I RFI* model

both evaluated the fate and transport of arsenic. However, in subsequent investigations selenium has been detected at elevated concentrations in groundwater.

The *Phase II RFI Work Plan* (Hydrometrics, 2010a) provided a scope for developing a new numerical groundwater flow and contaminant transport model for the Facility to simulate the fate and transport of arsenic and selenium.

Additional investigations were performed as part of the Phase II RFI to support the development of the groundwater flow and contaminant transport model including:

- Collecting soil samples to evaluate potential selenium source areas (see Section 6).
- Conducting leachability, sequential extraction, and batch adsorption tests on selected soil samples from onsite and offsite boreholes (see Section 6).
- Installing additional monitoring wells to further refine the CSM and further delineate the extent of the arsenic and selenium groundwater plumes (see Section 7).
- Measuring surface water flows in Prickly Pear Creek and Wilson Ditch to estimate leakage rates to and from groundwater (i.e., streamflow gain or loss, respectively) (see Section 8).

12.3 Model Development

As previously discussed, this Phase II RFI report is designed to support remedy selection and implementation activities at the Facility. This report is being issued concurrent with the initiation of the CMS, which will evaluate multiple remedial alternatives. As part of the CMS process, METG is developing a numerical groundwater model of the Facility to simulate the physical processes controlling the presence and movement of contaminants in onsite and offsite groundwater. The objectives of this work are as follows:

- The primary use of the numerical groundwater model will be to support decision-making regarding the feasibility and effectiveness of various soil and groundwater remedial activities under consideration. The modeling work and the evaluation of remedial alternatives under the CMS will consider various alternatives for onsite and offsite remedial measures whose objectives will be to:
 - Mitigate the presence of contaminants (primarily arsenic and selenium) in offsite groundwater.
 - Control and prevent further contaminant migration to offsite areas.
- For the selected remedies, the model will be designed to support the design of remedial systems and, during their implementation, evaluate their effectiveness in meeting remedial performance objectives.
- An additional modeling objective will be to evaluate the degree to which the offsite arsenic and selenium plumes are currently moving, or whether they are essentially stable and not expected to move further beyond the current mapped limits of these plumes.

A work plan describing the approach to model development is being prepared concurrent with the CMS and will be submitted to the Beneficiaries for review and approval in May 2011. The process of model development and application also are expected to result in continued improvements in (a) the understanding of the primary processes controlling contaminant migration and (b) the identification of uncertainties and data collection activities that could further enhance the remedial decision-making process and subsequent future evaluations of the effectiveness of remedial actions undertaken at the Facility.

The groundwater model will consist of a series of tools that each simulate specific physical processes controlling groundwater flow and contaminant migration in groundwater. A groundwater flow model will first be developed, using the USGS's MODFLOW-2005 software (Harbaugh, 2005). Contaminant transport modeling then will be conducted with the solute transport model MT3DMS (Zheng and Wang, 1999), and also may be supplemented with the PHT3D numerical model to simulate reactive transport for arsenic and selenium species, whose dissolved form is controlled by the aqueous geochemistry of the aquifer. The development of these models will be managed using the Groundwater Vistas Version 6 (GV-6) graphical user interface (Environmental Simulations, Inc., 2011). In addition to those core programs, modeling of areal recharge rates (from precipitation and irrigation) and leaching of contaminants from site soils and waste materials will be conducted using the HYDRUS model (Šimůnek et al., 2006; Šimůnek et al., 2008).

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13 Conclusions and Recommendations

This section presents a summary of major findings and conclusions of the Phase II RFI. Recognizing that investigation work is still underway at the Facility, this section also provides recommendations for addressing data gaps needed to support completion of the CMS, including the groundwater flow and fate and transport model. This section is organized to reflect major sections in this report.

13.1 Site Setting

13.1.1 Land and Human Use

The 142-acre Facility is located within the Helena Valley approximately 3 miles east of the City of Helena. Land uses in the Facility area include residential and commercial areas in the City of East Helena, rural residential areas in nearby subdivisions, and agricultural land and rangeland. Land use at the Facility and adjacent American Chemet site is classified as industrial. Current human use of the site is minimal because the Facility was shut down in 2001 and the main site use is associated with environmental cleanup activities. Public access to the Facility is restricted by fencing. Many buildings have been demolished and some contaminated soils beneath buildings have been excavated and disposed of in onsite CAMUs; residual contamination currently is capped with temporary HDPE liners. The most prominent site feature is a slag pile that currently occupies 35 acres in the northeastern portion of Facility.

Current and future residents in areas surrounding the Facility may contact groundwater, windblown dust, surface water, or sediment in creeks and ditches that contain contaminants derived from the Facility. Many rural residents in the Helena Valley (including the outlying areas around the Cities of Helena and East Helena) rely solely on private wells for their water supply.

13.1.2 Environmental Setting

Terrestrial habitat in and near the Facility includes vegetated upland areas outside the Facility perimeter, the sparsely vegetated area between Lower Lake and Upper Lake (referred to as Tito Park), and the riparian corridor along Prickly Pear Creek. Typical vegetation includes a variety of trees, shrubs, and grasses, which provides habitat for deer, small mammals, and upland game birds and predators (including red-tailed hawks, coyotes, and foxes), and supports livestock (primarily cattle). Within the Facility, habitat is limited by notable human disturbance; however, limited habitat exists for common species such as rabbits, squirrels, mice, and pigeons.

Aquatic habitats within and near the Facility exist in Prickly Pear Creek, Upper Lake and Upper Lake Marsh, Lower Lake, and Wilson Ditch. Upper Lake, Upper Lake Marsh, and Prickly Pear Creek provide a diverse range of habitats for benthic invertebrates, fish, amphibians, and aquatic plants. Lower Lake and Wilson Ditch (which flows seasonally) are man-made structures with lower quality habitat.

The BERA concluded that many upland and aquatic habitat areas have COPC concentrations in soil, sediment, and surface water that pose unacceptable risk to terrestrial and aquatic ecological receptors. The COCs for ecological receptors are arsenic, cadmium, mercury, lead, selenium, antimony, manganese, silver, thallium, and zinc. Areas of unacceptable terrestrial risks include uplands along the East and West Perimeter of the Facility. Risks to aquatic species were identified in Upper Lake and Upper Marsh, where suitable habitat exists.

13.1.3 Hydrogeologic Setting

The hydrogeologic framework is divided into three main hydrostratigraphic units:

- **Upper Aquifer** - The Upper Aquifer is the main focus of the groundwater investigation and the vast majority of the monitoring wells are completed in this unit. The Upper Aquifer is composed of silt and gravel, which varies in thickness from about 20 feet at the south end of the Facility to nearly 80 feet at the north end of Lamping Field.
- **Aquitard** - This unit, where present, marks the base of the Upper Aquifer and separates it from the underlying groundwater unit. The depth to the Aquitard increases from about 20 feet bgs at the south end of the Facility, 50 feet bgs at the north end of the Facility, and 80 feet bgs at the north end of Lamping Field. The thickness of the Aquitard is estimated to be approximately 12 feet near the middle of the Facility (DH-18).
- **Deeper Groundwater System** - Deeper groundwater lies beneath the Aquitard. Because the RFI and previous work focused on the Upper Aquifer, the thickness and hydrologic properties of the Deeper Groundwater System are largely unknown.

Groundwater beneath the Facility flows to the north/northwest and continues in a northwesterly direction offsite. Seepage from Upper Lake and Lower Lake on the southern property margin provides a significant source of recharge to the groundwater system, and provides a driving head that impacts groundwater flow gradients and velocities. Reducing seepage from Upper Lake and Lower Lake would have a significant effect on groundwater flow beneath the Facility. Seepage from Prickly Pear Creek, Wilson Ditch, and unlined irrigation ditches also provides localized recharge to the Upper Aquifer. Recharge from Prickly Pear Creek creates a flow divide at least as far north as Lamping Field that acts as a boundary restricting eastward migration of groundwater and contaminants downgradient of the Facility.

The reported hydraulic coefficients and steep gradients suggest unusually high groundwater flow velocities. Estimates of groundwater flow velocities (average linear) calculated using the reported hydraulic conductivities and measured gradients are as high as 50 feet/day or more. This velocity is very high considering the subsurface geologic materials and it is recommended this be confirmed before implementing corrective measures.

The groundwater hydrographs from paired wells in the Upper Aquifer and Deeper Groundwater System within the Facility confirm that hydraulic heads are on the order of 1

to 2 feet greater in the Deeper Groundwater System than in the Upper Aquifer. However, the overall seasonal patterns of the Upper Aquifer and Deeper Groundwater System appear similar, suggesting a similar recharge source. These preliminary conclusions may be significant in terms of interpreting Deeper Groundwater System chemistry and it is recommended this be confirmed with additional paired well and seasonal measurements.

13.2 Current Contaminant Conditions

13.2.1 Soil

Surface and subsurface soil contamination is significant and widespread throughout the Facility at concentrations up to approximately 1,800 times higher than levels considered protective of human health (e.g., industrial SLVs). Leaching of antimony, arsenic, cadmium, copper, lead, manganese, mercury, and selenium from surface and subsurface soil poses a widespread threat to groundwater quality within the Facility. Based on the results of the SPLP leaching tests, arsenic and selenium are the soil contaminants that have the greatest impact on groundwater quality. Specific areas exhibiting high metals concentrations included:

- Northwest corner of the CSHB
- The alignment of the buried pipe conveying water from Upper Lake to Wilson Ditch along the western Facility boundary (this area coincides with the former location of the Shew Ridge stockpile)
- The Lower Ore Storage Yard
- Tito Park
- The Former Acid Plant Drying Pads area

For arsenic, the highest arsenic concentrations in surface soils at the Facility are in the western half of the Facility, in the rail car staging area northwest of the Facility, and in the center of the Facility in the area of the former Acid Plant water treatment settling facility. In subsurface soils, arsenic is elevated throughout the Facility, with the highest concentrations occurring in the main processing areas of the Facility (the Acid Plant and Speiss/Dross Areas) and the lowest concentrations in the most downgradient locations. Arsenic concentrations generally appear to increase with depth; the highest arsenic concentrations in saturated soils typically occur near the water table. The Phase II RFI results show that leachable arsenic is present near the water table beneath much of the Facility (except in the most downgradient areas).

Compared with arsenic, areas with elevated selenium concentrations in subsurface soils are more limited, but the leachability test results suggest that the selenium is in a form that is fairly leachable and capable of generating solution concentrations that exceed groundwater SLVs. Selenium distribution maps and leaching results generated for the Phase II RFI indicate that there are only a few locations with elevated levels of selenium in saturated soils relative to the background concentrations. However, the highest concentration areas can serve as a continuing source of selenium to groundwater, and in fact, the selenium

plume originates in the area of the Facility correlating with the highest selenium concentrations in saturated soil (the former Acid Plant area).

The slag and underlying soil also may be an ongoing source area for the arsenic and selenium plumes. The data suggest that slag has the potential to leach arsenic and selenium at concentrations that exceed groundwater SLVs; however, that slag is heterogeneous and leachate concentrations are variable. Evaluation using potassium concentrations in groundwater as a tracer of slag leachate indicates the presence of a slag signature in groundwater.

13.2.2 Stormwater

Stormwater across much of the site is captured by a series of interconnected catch basins, temporarily stored in tanks and treated at the HDS water treatment facility. Stormwater collection and treatment is an important engineering control because samples of untreated stormwater from sumps and other locations across the Facility commonly showed SLV exceedances for arsenic, cadmium, and lead. Copper and selenium concentrations exceeded the project screening value in one sample from the Ore Storage Yard.

The HDS water treatment facility appears to be effective for most contaminants, with the exception of periodic detections of selenium in the effluent above the project stormwater SLV (13 of 66 samples between 2001 and 2010). Treated stormwater is discharged to Lower Lake under the Facility MPDES permit.

With the exception of periodic selenium exceedances in wastewater effluent, the interim stormwater controls that are in place appear effective. It is expected that stormwater management will be an important component of future corrective measures at the Facility to prevent uncontrolled runoff, minimize the infiltration of precipitation and leaching of contaminants to groundwater, and provide suitable treatment to allow discharge without degrading surface water.

13.2.3 Surface Water

Dissolved concentrations of arsenic, cadmium, iron, lead, selenium, and zinc were detected in one or more surface water sample locations at concentrations exceeding the project SLVs. Upper Lake and Lower Lake and the portion of Prickly Peak Creek immediately adjacent to Lower Lake have been identified as the primary AOPCs for surface water. In particular, contaminant concentrations in samples collected from Upper Lake and/or Lower Lake, on either side of Tito Park (the upland area of between the lakes), were significantly elevated in arsenic, cadmium, lead, and zinc. It is notable that dissolved COPCs measured in samples from Wilson Ditch are generally less than project SLVs and the ditch is not considered an AOPC for surface water.

An important element of the surface water system is the interactions with the underlying Upper Aquifer and how recharge from surface water influences groundwater flow and chemical migration. For example, site data clearly show that Upper Lake and Lower Lake are significant sources of recharge to the Upper Aquifer, and this will be an important consideration in designing future groundwater remedial measures.

While most of Prickly Pear Creek is a losing stream above and below the Facility, an analysis of groundwater and surface water levels shows that the reach in the immediate

vicinity of Lower Lake gains flow from groundwater discharge. Elevated arsenic concentrations in groundwater in this area suggest that groundwater is a likely source of arsenic to Prickly Pear Creek. Downstream (north) of the Facility, Prickly Pear Creek is a losing stream. The net fluxes from surface water to groundwater based on synoptic flow measurements of Prickly Pear Creek between Upper Lake and Canyon Ferry Road in August 2010 are estimated to be approximately 25 cfs.

Streamflow hydrographs of wells in the vicinity of Wilson Ditch show a rapid response to operation of the ditch, indicating a strong connection between the ditch and groundwater. Ditch losses of between 0.6 and 1.4 cfs to groundwater were measured during summer 2010 operations. Hydrographs for wells completed in both the Upper Aquifer and Deeper Groundwater System responded to flow in Wilson Ditch.

13.2.4 Groundwater

Within the Facility, the following dissolved metals were detected in the Upper Aquifer above project SLVs and, therefore, are identified as COPCs for groundwater: aluminum, antimony, arsenic, cadmium, lead, manganese, mercury, selenium, thallium, vanadium, and zinc. Of these, arsenic and selenium have the greatest number of SLV exceedances. Selenium is a highly mobile contaminant and has the largest plume footprint. The primary groundwater AOPC underlies the central portion of the Facility extending from Tito Park and Lower Lake downgradient beneath the former APSD and Speiss-Dross areas and is defined by selenium concentrations above the SLV.

As groundwater migrates northward from the Facility, concentrations of COPCs decrease and the number of SLV exceedances decreases. Offsite exceedance of groundwater SLVs is limited to antimony, arsenic, manganese, and selenium. Of these contaminants, antimony and manganese exceedances are restricted to a limited number of wells and these occur in areas encompassed by the arsenic and selenium plumes.

The vertical extent of contamination appears restricted to the Upper Aquifer. Existing paired well water level data show an upward hydraulic gradient between the Deeper Groundwater System and the Upper Aquifer within the Facility (well pairs DH-18 and DH-13). However, deep well data are limited, and additional wells and sampling are recommended to confirm that an upward hydraulic gradient between the Deeper Groundwater System and Upper Aquifer prevents downward migration of contaminants.

Selected residential and public water supply wells are being sampled regularly as part of the ongoing groundwater monitoring program to ensure protection of groundwater users downgradient of the Facility. Data collected to date indicate that the City of East Helena public water supply wells downgradient of the Facility have not been impacted by releases from the site. Arsenic and vanadium were the only analytes detected above SLVs in domestic wells. Additionally, concentrations of sulfate have been measured in private wells at concentrations above the SMCL.

A key conclusion of the groundwater investigation is that arsenic and selenium are the primary COPCs for groundwater because the extent of these plumes above project SLVs encompasses all other site-related contaminants. Based on this conclusion, a more detailed analysis of the sources, fate and transport of arsenic and selenium, was conducted in Section 11 of the Phase II RFI Report. Key findings and conclusions of this analysis are provided in the following sections.

Arsenic

There are significant ongoing sources of arsenic to groundwater at the Facility that include the following:

- Saturated zone soils appears to be the most significant ongoing source of arsenic loading to groundwater in the southern half of the Facility, particularly the Acid Plant, Speiss-Dross, and Tito Park areas. The thickness of arsenic contamination in saturated soils locally extends to depths greater than 20 feet.
- Unsaturated zone soils may be a source of arsenic to groundwater in certain areas of the Facility. High concentrations of arsenic in soils and SPLP leachate were obtained near the Acid Plant and Tito Park, both of which have relatively shallow groundwater.
- Surface water in Lower Lake is an ongoing low-level (0.1 mg/L) source of arsenic to groundwater. Some slag also produces leachate at concentrations that exceed the SLV for arsenic. The importance of these potential sources for ongoing loading will need to be evaluated further during calibration of the flow and transport model.
- Wilson Ditch may be a potential source of arsenic to groundwater; however, because surface water concentrations of arsenic are low, the primary mechanism for groundwater to be impacted is the leaching of arsenic adsorbed to underlying sediment by infiltrating surface water. One location where sediment leaching may influence groundwater is in an adjacent area in Lamping Field.
- The lateral extent of the arsenic plume appears to be relatively stable. This primarily the result of mineral sequestration (attenuation) during groundwater flow. Comparison of historical and recent arsenic data shows the highest concentration onsite areas of the plume have contracted during the last 8 to 10 years because process water, which was the primary source of arsenic, was eliminated in 2001. The depth-distribution of arsenic in saturated soils shows that arsenic has not appreciably penetrated the underlying clay and Tertiary units (i.e., the Aquitard).

Selenium

There are significant ongoing sources of selenium to groundwater at the Facility that include the following:

- The primary source of selenium is historical discharges of site process water. Evidence that supports this hypothesis includes the reportedly high concentrations of selenium in process water, and maximum site concentrations that coincide with other conservative tracers of process water (sulfate and chloride).
- Saturated soil may be the source of the lower concentration portions of the plume. Phase II RFI testing indicates there are only a few locations with levels of selenium in saturated soils that exceed the selected detection limit (Tito Park, Acid Plant, and Speiss/Dross Areas). Of these, leachate from the Acid Plant is greater than the selenium groundwater SLV, a result consistent with groundwater selenium SLV

exceedances in this area of the Facility.

- Unsaturated soils also may be a source of the lower concentration portions of the selenium plume, based on (1) the relatively high selenium concentrations found in soils at some surface soil sampling locations (e.g., upgradient of the thaw house and CSHB), and (2) leach testing that indicates unsaturated zone soils in this area may leach selenium in significant quantities.
- Slag is capable of leaching selenium at concentrations that exceed the groundwater SLV. The higher leachable concentrations of selenium from slag correlate with total concentrations, and occur in the central upper lift of the slag pile. This is the most recent slag added to the pile. Evidence for slag as a source includes the spatial distribution of selenium and potassium in groundwater in the eastern lobe of the selenium plume. The importance of slag will need to be evaluated further during calibration of the flow and transport model.
- Selenium is more mobile than arsenic, and footprint of the downgradient plume is larger than arsenic. The transient nature of the plume is consistent with the predominant chemical form of selenium in groundwater being Se(VI), the most mobile redox species. Because of the conservative (highly mobile) nature of this contaminant, dissolved selenium continues to migrate in groundwater downgradient of the Facility. This behavior contrasts with arsenic, which tends to be sequestered by minerals in the aquifer matrix.
- The mapped downgradient extent of selenium with a Facility source-signature extends over 2 miles downgradient of the Facility and is further empirical evidence of the mobile nature of this contaminant. However, it is important to note that selenium concentrations at downgradient margins of the plume are below project SLVs because of advective dispersion and dilution. The vertical extent of the selenium is also more expansive than arsenic. Additional monitoring of the Deeper Groundwater System is recommended to evaluate the presence or absence of selenium in the Deeper Groundwater System.
- There are insufficient historical selenium data downgradient of the Facility to draw firm conclusions about trends in concentrations at the downgradient plume margin. Whether the currently defined 0.05 mg/L selenium plume reaches downgradient locations most likely will depend on physical processes of dilution and dispersion, because attenuation of the dominant aqueous species (Se(VI)) is expected to be small. This hypothesis can be tested during calibration of the flow and transport model.

13.3 Recommendations

13.3.1 Characterization

The following recommendations are provided to address data gaps associated with characterization of the nature and extent of Facility contaminants and aquifer characteristics:

1. Further define the horizontal and vertical distribution of the selenium plume downgradient of the Facility where the Upper Aquifer thickens. This may require installation of deeper wells within the Upper Aquifer and/or sampling at discrete intervals within existing wells.
2. Confirm the presence and thickness of the Aquitard that separates the Upper Aquifer and Deeper Groundwater System beneath and downgradient of the Facility. Most wells are completed in the Upper Aquifer above the Aquitard. The presence and competency of this unit is an important factor in evaluating potential groundwater remedial measures.
3. Install additional deep/shallow piezometer pairs to gather long-term water level and water chemistry information in the Deeper Groundwater System, and allow evaluation of the potential vertical connection between the zones.
4. Conduct multi-well/multi-depth pumping tests to confirm horizontal and vertical hydraulic conductivities and collect empirical measurements of aquifer response to pumping. The current hydraulic coefficients are mostly based on single well tests and may not accurately represent bulk aquifer conditions. Pumping tests are recommended to accurately define bulk hydraulic conditions to support the groundwater flow model and evaluation, and design of potential corrective measures.
5. Determine if groundwater pumping and underground injection activities at the adjacent American Chemet facility may be influencing groundwater flow and/or contaminant migration at or downgradient of the Facility.
6. Better characterize the source of selenium in stormwater effluent. Also conduct an evaluation of the wastewater treatment plant to determine if additional reduction in selenium in the effluent can be achieved.
7. Continue monitoring offsite drinking water wells to ensure contaminant concentrations remain below protective threshold criteria.

13.3.2 Considerations for CMS

1. It is essential to develop a calibrated numerical groundwater flow and transport model to allow evaluation and selection of appropriate remedial measure alternatives. This model should be used to predict groundwater plume stability, evaluate the feasibility and effectiveness of various groundwater remedial actions, evaluate effectiveness of source control measures, support remedial design activities, and provide a predictive capability that will support risk-based decision making.

2. Evaluate the feasibility of closing Lower Lake to remove this as an ongoing chemical source and driving head to the Upper Aquifer. This action also may have a positive impact on water quality in Prickly Pear Creek.
3. Evaluate the removal of highly contaminated soil in the Tito Park area. These soils are an ongoing source of contaminants to surface water and groundwater.
4. Evaluate re-routing, lining, or piping water in Wilson Ditch to eliminate seepage to groundwater and potential exposure to residents living adjacent to the ditch in the Manlove neighborhood.

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SECTION 14

14 References

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